ISOTOPES AND RADIATION TECHNOLOGY

A Quarterly Technical Progress Review

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ISOTOPES INFORMATION CENTER

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ISOTOPES INFORMATION CENTER

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Erratum: On page 90 of Vol. 5, No. 2, "berkelium" should read "californium" in the third line above the subheading "Production in Reactors."

Isotopes and Radiation Technology

is a Technical Progress Review prepared by the Isotopes Information Center, Oak Ridge National Laboratory, at the request of the Divisions of Technical Information and Isotopes Development, U. S. Atomic Energy Commission. This Review is intended to assist those interested in keeping abreast of significant developments in the fields of isotopes and radiation technology. It is not a comprehensive review of all literature published in this field during a given quarter; rather, it is a mechanism for presenting concise, selected reviews of information on subjects of prevailing Commission interest as it becomes available.

This Review attempts to relate the published results of research and development sponsored by the Division of Isotopes Development to significant developments in radioisotopes and radiation technology, as reported in the world literature. Coverage includes isotope production and development, isotope technology development, isotope applications technology, process radiation development, and radiation processing of food and medical supplies.

In addition to reviews of current literature and special review articles dealing with specific isotopes, facilities, and applications, this publication occasionally contains feature articles prepared by recognized experts on specific topics of current interest. Critical evaluations and interpretations presented are those of the editors and invited reviewers; therefore readers are encouraged to consult the original references in order to obtain all the background of the work reported and the interpretation of the results given by the original authors.

The subject headings listed below have been adopted to help maintain continuity and order, from one issue to the next, in the material reviewed. All reviews, except Feature Articles, will be arranged under these headings; but any one issue will not necessarily contain all the headings.

Isotope Production and Development
Isotope Technology Development
Food Irradiation
Process Radiation Development
Source Development
Isotopic Heat and Power Development
Applications in Life Sciences
Safety
Isotopes Around the World
Miscellaneous

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Oak Ridge National Laboratory

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The United States Atomic Energy Commission publishes the Technical Progress Reviews to meet the needs of industry and government for concise summaries of current nuclear developments. Each journal digests and evaluates the latest findings in a specific area of nuclear technology and science. *Nuclear Safety* is a bimonthly journal; the other three are quarterly journals.

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Nuclear Safety
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Reactor and Fuel-Processing Technology
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Reactor Materials
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Battelle Memorial Institute

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Other U. S. Government agency reports identified in this journal generally are available from CFSTI.

Private-organization reports should be requested from the originator.

United Kingdom Atomic Energy Authority (UKAEA) and Atomic Energy of Canada Limited (AECL) reports are available at USAEC depository libraries. UKAEA reports are sold by Her Majesty's Stationery Office, London; AECL reports are sold by the Scientific Document Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada. UKAEA and AECL reports issued after March 1, 1967, are sold by CFSTI to purchasers in the United States and its territories.

Section I

Isotopes and Radiation Technology

Isotope Technology Development

Tracing with Activable Tracers. Part I*

By R. E. Greene

Abstract: The use of activable stable isotopes and stable elements with various types of activation analysis for tracing is reviewed. Advantages and disadvantages of the method are given, and several examples of applications of tracing with activable tracers in medicine and biology, pollution studies, hydrology, industry, and metallurgy and related fields are described. (In several parts.)

Much has been written on tracing and tracking materials using radioisotopes, and the successful application of radiotracer techniques has been demonstrated in a multitude of instances. However, there are situations where the use of radioisotopes is inadvisable because of safety or public relations considerations. Nevertheless, a nuclear method may still be used for a wide variety of tracing, and, in some cases, may be used for elements that have no radioisotopes suitable for the usual type of radiotracing, i.e., where the radioisotopes either are of too short half-life or have radiations too weak for easy detection. This nuclear method involves the use of a stable nuclide or element as the tracer, and, after the tracing test has been completed, the isotope or element in a sample from the system under study is determined by some type of activation analysis. Thermal-neutron activation analysis is commonly used, but such methods of activation as fast neutron, proton, and gamma ray are also used. In many instances the activation method is as sensitive as the conventional radioisotope tracing method.

The method is especially useful in applications where radioisotopes are undesirable or can be used only with great reluctance — for example, for in vivo studies in humans, tracing of potable water, and air-pollution studies.

Three types of stable tracers may be used: (1) An enriched stable isotope of an element already present in the matrix may be added for the tracing study; (2) an element (or enriched stable isotope) different from the matrix but with suitable nuclear (activation and radiation) properties may be added to the matrix; or (3) a minor (stable) element occurring in the matrix may be used for tracing (e.g., manganese to detect the wear of steel). Examples of all three types will be given in various fields of application.

Of the three types, the first seems to be the preferred method since the stable isotope of the element being traced will either react or not react with its environment exactly as the element being studied. In many instances more than one stable isotope of an element is available, thus giving a choice of induced nuclear properties after activation.

Guinn[1] discussed four criterions that stable-isotope tracer studies, followed by thermal-neutron activation analysis, should meet to an appreciable degree:

1. The natural abundance of the stable isotope used should be low, preferably less than 10%.
2. The stable isotope should be commercially available, at moderate cost, in enrichments preferably greater than 10 times the natural abundance.
3. The thermal-neutron capture cross section (n,γ) of the isotope should be appreciable, preferably greater than 0.1 barn.
4. The product from the (n,γ) activation of the stable isotope should have a half-life of days or less and should emit readily detected radiations, preferably gamma radiations.

Guinn listed 53 stable isotopes of 31 different elements that satisfy to a reasonable degree the above criterions as well as the maximum enrichment ratios available for stable isotopes of these 31 elements. This list of isotopes and elements would, of course, be expanded if other types of activation analysis were included.

*This review will be presented in several parts: Part I describes the use of activable tracers in medicine and biology and in air-pollution studies; applications in hydrology, industry, and metallurgy and related fields will be described in subsequent issues.

Sources of enriched stable isotopes are listed in *The Isotope Index*,[2] and Oak Ridge National Laboratory, the world's largest producer and supplier of enriched stable isotopes, although not listed in this publication, lists in its catalog[3] approximately 250 stable isotopes in various degrees of enrichment.

The advantages and disadvantages of activable-tracer methods are:

Advantages

1. No radioactivity is added to the medium, material, or host (in medicine or biology) under test.
2. No handling of radioactive materials or of the associated heavy shielding is required in the field. Likewise, electronic detectors, counters, etc., need not be taken into the field.
3. No license is required for the use of enriched stable isotopes. (For medical applications, however, enriched stable-isotope compounds must meet any applicable FDA regulations.)
4. In many applications the activation method is nondestructive; therefore a sample may be analyzed repeatedly to enhance the precision of the particular determination.
5. In many instances sensitivity is equal to that of radiotracer methods and superior to that of chemical and physical tracer methods.
6. In large-scale tests, radioisotopes may be prohibitively expensive; where an element rather than a stable isotope may be used as an activable tracer, costs could be quite reasonable.
7. Some elements for which there are no suitable radiotracers can be traced by this method, for example, oxygen and, in some cases, hydrogen (^{3}H has such a weak beta radiation, E_{max} = 0.0186 Mev, it is difficult to detect, especially in the field).
8. The equipment cost for nuclear determination of stable isotopes (and elements) is in many instances (especially if a reactor is available) less than that of a mass spectrometer. Service irradiations may be obtained from commercial reactor installations for modest fees.
9. Stable isotopes do not decay; therefore the duration of the tracer test is not limited by a half-life, and no decay corrections are required for the time the isotope (or element) is in the system under study. (Of course, decay corrections from the time of activation must be considered.)

Disadvantages

1. Results often are not so prompt; except for on-line systems, samples must be taken and analyzed later in the laboratory.
2. Costs of some stable isotopes may be more expensive than radioisotopes. (However, some of the stable isotopes are much less expensive than the equivalent required amounts of radioisotopes.)
3. The analyses require activation either in a reactor or with an accelerator, which may not be conveniently available.

This review does not give calculations for the amounts of tracer required, the degree of activation required, or details of counting methods, since much of this information is given in the cited references. Also, although this review is not all inclusive, several applications of tracing with activable tracers in the fields of medicine and biology, pollution studies, hydrology, industry, and metallurgy will be described. This review is limited to activation methods and does not include methods of analysis other than nuclear, e.g., mass spectrometry. X-ray fluorescence analysis techniques are being developed and may further extend the usefulness of stable element tagging and the choice of elements that can be used.

Medicine and Biology

One of the greatest advantages of the activable-tracer method in the fields of medicine and biology is that it does not subject the system under study to any radiation hazard. This is especially important with infants, pregnant women, and children.

CALCIUM

One of the most successful uses of the activable-tracer method in medicine has been with the stable calcium isotopes—^{46}Ca and ^{48}Ca. McPherson[4] has made extensive use of these nuclides as tracers in studies of mineral metabolism. His investigations describe the application of the two isotopes as tracers of calcium in man and in animals. The abundances of ^{46}Ca and ^{48}Ca in 10-mg samples of calcium are determined indirectly by activation analysis and measurement of the induced radioisotopes—^{47}Ca (4.5 days) and ^{49}Ca (8.8 min), respectively—with gamma spectrometry combined with direct ethylenediaminetetraacetic acid (EDTA) titration of total calcium in the activated samples. Interfering elements are removed by simple chemical procedures before activation.

Studies of the ratio of the specific activities of ^{47}Ca in serum and urine in man failed to demonstrate a biological isotope effect; fractionation of heavy calcium isotopes is not great enough to affect calcium tracer studies. The 10-mg samples for activation can be isolated from timed urine collections and are representative of the isotopic abundance pattern of serum. Parallel studies in man and in animals with the radioisotope ^{47}Ca and the stable isotope ^{48}Ca show that these two tracers are similarly distributed.

The dose of stable isotope used is calculated in relation to the expected pool size, length of study, enrichment of isotope available, and amount of calcium in the dose (which may affect equilibrium in

the system studied). In this regard the use of ^{46}Ca is advantageous because of its low natural abundance (0.0033%).

When ^{48}Ca is used as a tracer in children, the exchangeable calcium pool can be estimated 24 hr after injection. Application of stable calcium tracers to the estimation of this as well as of other parameters of calcium kinetics in such radiosensitive subjects should lead to an increased understanding of the physiology of skeletal growth.

The use of ^{48}Ca as a stable tracer in studies of mineral metabolism in man was also reported in earlier work by McPherson.[5] Abundance estimates of ^{48}Ca in urine samples expressed as percentage of dose per gram of calcium and comparative data on ^{47}Ca were given.

Since $^{48}Ca/^{40}Ca$ ratios of plasma and urine are the same at any given time, knowledge of the urine ratio enables plasma curves to be constructed. The 2- to 5-mg samples needed for activation could be isolated from urine, avoiding the need for larger blood samples. Measurements of ^{48}Ca by mass spectrometry were also given.

Smith and Bethard,[6] in collaboration with the Endocrine Division of the Children's Hospital of Los Angeles, have recently conducted some studies using ^{46}Ca on the residence time of calcium in patients with bone diseases. Approximately 1 mg of total calcium, enriched between 25 and 40% in ^{46}Ca, was intravenously injected into the patients. Complete stool and urine specimens were collected before and 2 or 3 weeks after administration of the enriched ^{46}Ca isotope.

Samples of calcium, separated from the samples as oxalate, were irradiated in the shuttle tube of the General Electric Test Reactor to give ^{47}Ca by the $^{46}Ca(n,\gamma)^{47}Ca$ reaction. After a decay period to reduce the short-lived activities, the samples were put through a decontamination step and converted to nitrate solutions. The samples were counted in a 3- by 3-in. well type NaI(Tl) crystal coupled to a 3-in. photomultiplier tube connected to a 256-channel analyzer. The area under the 1.31-Mev gamma photopeak was measured. Smith and Bethard, because of uncertainties in the literature values, also determined the half-life* of ^{47}Ca in four calcium standards.

Peisach and Pretorius[7] have used proton activation in the isotopic determination of ^{43}Ca in tracing with stable isotopes. Irradiation of ^{43}Ca with 4.75-Mev protons, which are above the coulomb barrier of 4.1 Mev, gives 44-hr ^{43}Sc [$^{43}Ca(p,n)^{43}Sc$] as well as 3.9-hr ^{43}Sc and 4.0-hr ^{44}Sc. For the proton energy used, the (p,n) reaction is impossible with ^{40}Ca (90.97% abundant) and ^{42}Ca (0.64% abundant). Thus the main activities expected will be from the 43, 44, and 48 scandium isotopes. The yield of ^{46}Sc is expected to be low because of the very low (0.0033%) abundance of ^{46}Ca and the relatively long half-life of ^{46}Sc (84 days). The ratio of activities from ^{43}Sc and ^{44}Sc to that of ^{48}Sc gives a measure of the isotopic concentration of ^{48}Ca. The relative standard deviation over the concentration from 0.18 (natural) to 4 at.% ^{48}Ca is 2.7%. The method, being based on the determination of activity ratios, does not require that yields, target weights, or irradiation fluxes be known. The method is not suitable for microamounts of calcium—about 1 mg of calcium fluoride is the minimum required for the target preparation by vacuum distillation; however, this quantity is usually readily obtainable from most biological systems.

Junod and Laverlochere[8] have also studied the possibilities of using neutron activation analysis to determine stable ^{43}Ca as a tracer in a medium containing natural calcium. Interferences were studied, and ^{43}Ca was determined in samples of calcium carbonate from tracer experiments. The sensitivity for the determination of natural calcium, calculated from ^{43}Ca, was of the microgram order.

IRON

Lowman and Krivit[9] have described an in vivo tracer method using stable ^{58}Fe and activation analysis. They used ^{58}Fe enriched to 78.8% (natural abundance, 0.33%) as sterile ferrous citrate.

First, in an in vitro recovery study of ^{58}Fe from human plasma, reproducibility and accurate quantitation at low tracer concentrations were demonstrated. One-milliter aliquots of an unenriched plasma blank and of each of several dilutions from 0.1 to 0.0125 mg of ^{58}Fe per milliliter of pooled human heparinized plasma were placed in 99.99% pure aluminum containers, which were then heated at 90°C for 20 min or until the plasma was a firm gel. The samples were activated in the research reactor at Brookhaven National Laboratory, the reaction being $^{58}Fe(n,\gamma)^{59}Fe$ (half-life, 45 days). Fourteen days after removal from the reactor (to allow for decay of ^{24}Na and ^{42}K), the samples were placed in a 400-channel analyzer and the counts under the 1.28-Mev peak were corrected for decay and multiplied by their respective weight-correction factors. Recovery studies of ^{58}Fe showed reproducible, quantitative results.

Plasma-clearance rates of both the radioisotope ^{59}Fe and the nonradioactive ^{58}Fe were studied in vivo following their simultaneous injection in male medical-student volunteers. Iron-58 was determined by activation analysis, and the ^{59}Fe was counted with a single-channel pulse-height analyzer. (Corrections in the activated-^{58}Fe studies for the simultaneously injected ^{59}Fe were considered, but the time required to com-

*The half-life value of ^{47}Ca determined by Smith and Bethard[6] (4.50 ± 0.03 days) is in good agreement with the value recently determined at Oak Ridge National Laboratory by Reynolds, Emery, and Wyatt (4.530 ± 0.004 days); see Half-Lives of Radionuclides—III, *Nucl. Sci. Eng.*, 32: 46-48 (April 1968).

plete the studies and the relatively short counting period for the activated samples reduced the original ^{59}Fe counts in stored aliquot controls to undetectable levels.) From the data, nearly identical ^{58}Fe and ^{59}Fe plasma-clearance curves were obtained for the two representative in vivo studies. Small differences in the rates demonstrated by the two isotopes are less than expected for duplicate radioisotope studies and are within the variation of the counting statistics alone. The correlation indicated that ^{58}Fe is cleared and handled in the body the same as ^{59}Fe. Iron has obvious useful applications as a tracer in hematological studies, and the stable-isotope activation technique is bringing these studies into use in newborns and infants. Lowman and Krivit also listed many common isotopes that can be used with this technique.

In an earlier work Lowman and Krivit[10] presented the general theoretical aspects of activation analysis and, in particular, the theoretical requirements for the use of ^{58}Fe as a tracer. They pointed out some interesting discoveries and problems encountered in standardizing a tracer study using this isotope.

Wahl, Nass, and Kramer[11] reviewed the work of McPherson[4] and Lowman and Krivit[9] in some detail.

STRONTIUM

In the study of strontium metabolism, where the use of a radioactive tracer was not allowed in some types of people, e.g., young children, Smith[12] used a stable isotope of strontium—^{84}Sr, 0.56% natural abundance—which could be detected easily in small amounts against the normal body background. The use of a very small amount of stable tracer was important because even 1 mg of strontium may upset the normal balance and render the studies invalid. Strontium enriched to 50% ^{84}Sr was used. Calcium and strontium recovered from body fluids and digested materials were precipitated twice as the oxalate, and the weight was determined. These samples, along with a strontium carbonate standard, were irradiated in a reactor for 1 week. No accurate knowledge of neutron flux or activation cross section is required since measurements are gaged against the standard sample, which is irradiated simultaneously in the same pack and from which, after chemical recovery, yields are standardized. After irradiation, the samples and inactive carrier were dissolved in 16*M* HNO_3, calcium was recovered by precipitation with potassium ferrocyanide, and barium was removed by precipitation as the chromate. Strontium was then precipitated as the carbonate and the recovery determined gravimetrically. The activity of the ^{85}Sr from the $^{84}Sr(n,\gamma)^{85}Sr$ reaction was measured with a scintillation spectrometer and compared with that of the standard. Smith reports that application of activation analysis of ^{84}Sr to micro estimations permitted amounts of about 10^{-9} g to be detected with ease. Tests on solutions of known ^{84}Sr content gave results in the range of ±1% of the calculated value, and biological samples varying in known ^{84}Sr content from 10^{-8} to 10^{-6} g, when analyzed by this method, gave results that were in the range of ±2% of the calculated value.

IODINE

Iodine-129, although it may be used in many various tracing applications, has characteristics that make it attractive for medical and biological use. This isotope, a fission product that is only slightly radioactive (half-life of 1.6×10^7 years), has been used as a so-called "stable" tracer and determined by activation-analysis techniques. Besides its long half-life, it has very-low-energy radiations, 0.150-Mev β^- and 0.038-Mev γ. Its low specific activity and weak gamma energy preclude its use as a direct radioactive tracer in most applications since it cannot be counted efficiently using scintillation detectors with pulse-height discriminators. Its relatively high thermal-neutron capture cross section, 28 barns, is a property favorable for determination by neutron activation.

Edwards[13] has discussed the occurrence of ^{129}I in nature and described its use as a tracer. He listed several advantages of the use of the ^{129}I-activation method for iodine tracer studies. These include the extremely low natural abundance, possible use as a second label with ^{131}I or ^{125}I, and a sensitivity of 10^{-13} g. The net result of the sensitivity attainable makes possible the tracing of 1 g of ^{129}I through processes that result in dilution factors up to 10^{13}, which is equivalent to dilution sensitivities attainable with about 350 curies of any radionuclide.

Edwards[14] has also been awarded a U. S. Patent on the method of tracing iodine using ^{129}I and neutron activation analysis.

Studier et al.[15] have developed a neutron activation procedure intended to make ^{129}I useful as a tracer. Their procedure involves isolation of an iodine fraction from a variety of samples by high-temperature ignition in a stream of oxygen; no carrier is added, but ^{131}I is added for determination of the yield. A ^{127}I monitor with a known amount of ^{129}I is irradiated in a moderated neutron flux adjacent to the sample. The sample and monitor are decontaminated from extraneous activities for measurement and resolution of various iodine activities. Specific activities in the monitor of ^{128}I [from $^{127}I(n,\gamma)^{128}I$], ^{130}I [from $^{129}I(n,\gamma)^{130}I$], and ^{126}I [from $^{127}I(n,2n)^{126}I$] are determined. By direct comparison of these activities with the same activities in the sample and correcting for chemical yield, both the ^{127}I and ^{129}I contents of the sample may be determined. An advantage of the procedure is that the natural iodine (^{127}I, 100% abundant) content

of the sample is determined at the same time. Samples were irradiated at a flux of 3×10^{13} n/(cm^2)(sec), and amounts as small as 10^{-10} g of ^{127}I and 10^{-13} g of ^{129}I could be determined.

Watson, Roe, and Selenkow[16] have made a preliminary study to explore the applicability of ^{129}I to biological systems and to stimulate further research into its use in thyroid investigations and as a molecular label for proteins. For qualitative purposes, a milligram of ^{129}I-labeled thyroxine was irradiated for 1 min at a flux of 8×10^{12} n/(cm^2)(sec) to observe the effects of radiation on the organic matrix. The ^{130}I gamma spectrum was clearly discernible when the sample was counted with a 3- by 3-in. NaI(Tl) crystal and a multichannel analyzer. In quantitative studies aliquots of a standardized stock solution of H^{129}I were diluted and irradiated for 1 hr at 8×10^{12} n/(cm^2)(sec) to obtain a plot of activity vs. quantity. The minimum quantity of H^{129}I that was successfully measured was 2×10^{-9} g. Argon-41 interference from the irradiation of ^{40}Ar in air [^{40}Ar $(n,\gamma)^{41}$Ar] was remedied by gently warming the solution from the "hot" vials, which reduced the solubility of argon in the solutions.

These authors stress that the relatively long half-life of ^{130}I (12.5 hr) in contrast to other measurable radioactive halogen nuclides, e.g., ^{128}I (25 min) and ^{38}Cl (37.3 min), provides an exceptional advantage for the use of ^{129}I in biological studies. In addition, the preparative procedures of Smith, Mozley, and Wagner[17] for the determination of protein-bound iodine (^{127}I) by activation analysis are equally applicable to ^{129}I in complex biological mediums and have several advantages for use in dynamic studies of thyroid function and as a label for organic compounds.

Ouellette, Balcius, and Zuppinger[18] have developed a neutron activation technique using ^{129}I for the determination of iodinated compounds in the blood serum. Briefly, their procedure involves (1) labeling of the iodine pools with ^{129}I; (2) paper chromatographic separation of 5-monoiodotyrosine (MIT), 3,5-diiodotyrosine (DIT), 3,5,3′-triiodothyronine (T3), and 3,5,3′,5′-tetraiodothyronine (T4) with a solvent system of n-butanol saturated with 2M acetic acid; (3) neutron irradiation of the paper strips [^{129}I$(n,\gamma)^{130}$I]; (4) resin chromatography to remove impurities; and (5) pulse-height analysis using a 1.75- by 2-in. NaI(Tl) crystal and a 256-channel analyzer. Labeling time and concentration of iodide, MIT, DIT, and T3 plus T4 in rat blood serum were determined. Results indicated that approximately 35% of the iodine in blood is in the form of MIT and DIT. The sensitivity of the method is 10^{-11} g of iodine, and recovery is 99.9%; however, the proposed procedure is essentially a tool to be used in research where a possible low limit of detection of 10^{-14} g of iodine (under ideal conditions) and a recovery of better than 99% are essential.

COPPER

In a study on tracing of snake venom in animal tissues and the possible contribution to the kinetics of its spread, Moav et al.[19] are attempting to use in vivo labeling of copper enriched in the ^{65}Cu isotope. Dialyzed venoms have been shown to contain large concentrations of copper (~1000 ppm) and zinc (~500 ppm). Two difficulties were encountered in tracing the spread of venom by conventional activation analysis of copper: (1) the small amount of venom (~1 mg containing ~1000 ppm copper) is diluted by a factor of >1000 in larger quantities of tissue (containing 1 to 10 ppm copper) and (2) the natural distribution of copper in the tissues of experimental animals varies greatly (±50%). Attempts are being made to use in vivo labeling of the venom with copper enriched in ^{65}Cu and to use the ^{65}Cu/^{63}Cu isotope ratios determined by activation analysis for tracing. The natural abundances of the copper isotopes are 69.09 and 30.91% for ^{63}Cu and ^{65}Cu, respectively, and the ^{65}Cu/^{63}Cu natural-abundance ratio is 0.44. If a ^{65}Cu/^{63}Cu ratio of 8 can be attained in the venom using enriched ^{65}Cu, the venom copper can be determined by activation analysis in spite of the dilution in the tissues. Histological, biochemical, and toxicological methods of investigating the spread of snake venoms and their concentrations in tissue have so far yielded only indirect evidence of actual presence of the venom in the tissues. Hopefully, this method may contribute to a better understanding of the kinetics of its spread.

OXYGEN

Several nuclear methods have been used for determination of stable oxygen in biological tracer studies. In one of the earlier works, Fogelström-Fineman et al.[20] used enriched ^{18}O and activation analysis, taking advantage of the ^{18}O$(p,n)^{18}$F reaction. The initial purpose of their work was to determine qualitatively, and quantitatively if possible, the oxygen that is incorporated in different compounds in algae grown in ^{18}O-enriched water (20% ^{18}O) for short periods of time. Alcohol extracts of the algae were concentrated and separated by paper chromatography in one dimension, using butanol–propionic acid–water solvent. Since the paper contained natural ^{18}O, a method was devised to transfer the separated compounds on the paper to a tantalum metal sheet before bombarding the material with protons. The presence of ^{18}O on the irradiated metal strips was confirmed by gamma-ray spectrometry by measuring the decay of the annihilation peak at 0.51 Mev, which corresponds to ^{18}F, a β^+ emitter formed by the proton bombardment of ^{18}O. In the experiments with algae, the separated fractions were transferred from the paper to the tantalum plate and activated by proton bombardment, and the ^{19}F was determined by autoradiography. In a test to determine the sensitivity of

the method, a spot on the autoradiogram representing as little as 2 μg of algae and 0.1 μg of ^{18}O could still be detected against the background.

Fleckenstein and Janke[21] have also used proton bombardment for tracing ^{18}O. They measured the incorporation of ^{18}O coming from $H_2{}^{18}O$ under different physiological conditions in molecules of adenosine triphosphate (ATP), phosphocreatine, mineral phosphate, and other phosphorus compounds in the cardiac and skeletal muscles. Their results showed the advantages of this new method with respect to the traditional use of radiophosphate. The incorporation of radiophosphate in the intracellular phosphorus compounds is strongly inhibited by the membrane of the muscle fiber, whereas $H_2{}^{18}O$ rapidly arrives at the intracellular sites where the metabolic reactions of the phosphoryl compounds take place. For this reason the acceleration of the metabolism of ATP and phosphocreatine provoked by an electrical stimulation can be detected only with $H_2{}^{18}O$.

Guinn[1] also has found that ^{18}O can be sensitively determined by the $^{18}O(p,n)^{18}F$ reaction, but with one difference—he used recoil protons produced in situ by collisions with reactor fast neutrons rather than the conventional accelerator-produced protons that are commonly used in the reaction. Guinn found that, after irradiation in the pneumatic-tube core position, normal counting techniques, and brief counting of the 0.51-Mev positron-annihilation photopeak of ^{18}F, the limit of detection was the amount of ^{18}O in only 2 mg of natural water (^{18}O abundance, 0.204%). With longer counting periods and the use of a coincidence-pair spectrometer, detection sensitivity can be further improved.

Solberg, Wethington, and Parkinson[22] have used a different nuclear reaction for the quantitative determination of ^{18}O by activation analysis. Because of the low cross section of ^{18}O for thermal neutrons (2×10^{-4} barn) and the short half-life of the product nuclide, ^{19}O (29 sec), little use has been made of thermal neutrons in the reaction $^{18}O(n,\gamma)^{19}O$. These workers have shown that the determination of ^{18}O and of $^{18}O/^{16}O$ ratios is practical by activation analysis with thermal neutrons. Samples of water with ^{18}O concentrations ranging from 0.204 at.% (natural abundance) to 10.79 at.% were irradiated for 4 min in the University of Florida Training Reactor at a flux of 7.2×10^{10} n/(cm^2)(sec). The minimum amount of ^{18}O detectable with their equipment was approximately 350 μg, but an increase in the flux to $\sim 10^{14}$ n/(cm^2)(sec) would lower this limit to 0.2 μg. They concluded that thermal activation analysis of ^{18}O can definitely be used as an analytical method for $^{18}O/^{16}O$ isotope-ratio studies and that the method is particularly suitable for oxygen-metabolism studies in living systems. Preliminary results obtained on the uptake of ^{18}O in corn seedlings exposed for varying times to an atmosphere containing 10 at.% ^{18}O confirm the usefulness of the method for oxygen-metabolism investigations.

Amiel and Nir[23] have used the $^{18}O(\alpha,n)^{21}Ne$ nuclear reaction to determine ^{18}O in various ^{18}O-labeled substances by bombarding the samples with alpha particles from a radioactive source and counting the neutron emissions produced. Thick-target yields per 10^6 alpha particles were 28.4 ± 2 neutrons from ^{210}Po (E_α = 5.3 Mev), 400 ± 25 neutrons from ^{228}Th (E_α = 5.4 to 8.8 Mev) in equilibrium with its daughters, and 150 ± 10 neutrons from an active deposit (daughters) of thoron (^{220}Rn, E_α = 6.1 to 8.8 Mev). Amiel and Nir found the output of neutrons from ^{18}O-labeled samples to be proportional to the ^{18}O content. In the analysis of paper chromatograms, sensitivities in the range of tens of micrograms of ^{18}O per square centimeter were obtained with fluxes of $\sim 10^7$ alpha particles per second from an active deposit of thoron. The main source of background was the natural oxygen present in paper or other sample matrixes. Potential interferences are Be, B, Li, and F; the last two cause an appreciable background only when present in proportions comparable to that of ^{18}O. The principle of the method offers the possibility of instantaneous, continuous, and nondestructive determination of ^{18}O in various types of samples—gases, liquids, solids, or paper chromatograms.

Amiel and Peisach[24] have described a method for determining ^{18}O by counting delayed neutrons from ^{17}N. Nitrogen-17 is produced by the successive nuclear reactions $^6Li(n,\alpha)T$, $^{18}O(T,\alpha)^{17}N$. The amount of lithium in the solution to be analyzed for ^{18}O must be known. When the sample is irradiated to saturation in a thermal flux of 4×10^{13} n/(cm^2)(sec), the total delayed-neutron emission is about 4×10^5 n per milligram of ^6Li per atom percent of ^{18}O. The ^{17}N formation is proportional to the atom fraction of ^{18}O and is independent of sample size. From statistical considerations the authors suggest, for example, that a drop-size (33 μl) sample of water containing 1 at.% ^{18}O and 40 μg of ^6Li could be analyzed with a standard error of 4% ^{18}O, using a single irradiation at 10^{13} n/(cm^2)(sec) and counting with an efficiency of 10%. In larger samples, where the ^6Li content can be increased, the count increases correspondingly with increasing ^6Li content and the errors become smaller.

Guinn, Kleinstein, and Mull[25] have studied the feasibility of the nondestructive determination of ^{18}O by activation with 14-Mev neutrons from a small neutron generator. The gamma radiation from the 2.25-sec ^{15}C formed by the reaction $^{18}O(n,\alpha)^{15}C$ is detected. The gamma activity of the 7.35-sec ^{16}N from the $^{16}O(n,p)^{16}N$ reaction interferes with the ^{15}C spectrum. By subtracting the pulse-height spectrum of an activated normal water sample from that of an enriched water sample (70% ^{16}O and 30% ^{18}O), a very good, pure spectrum of ^{15}C was obtained with a well-defined photopeak at 5.30 Mev.

NITROGEN

Very little is found in the literature for the determination of stable isotopes of nitrogen by activation. Stable ^{15}N, used extensively in medical and biological research, is usually determined by mass spectrometry. Guinn et al.[1] have shown that ^{15}N can be determined by activation analysis using a small Cockcroft–Walton deuteron accelerator to give 14-Mev neutrons from the $T(d,n)^4He$ reaction to induce the $^{15}N(n,p)^{15}C$ reaction. The 2.25-sec ^{15}C emits a 5.30-Mev gamma ray. If the sample to be assayed contains appreciable amounts of oxygen, the ^{15}C photopeak is obscured by the radiations from ^{16}N formed by the $^{16}O(n,p)^{16}N$ reaction, which has a 6.13-Mev photopeak and 5.62- and 5.11-Mev escape peaks. Spectrum stripping was found to subtract the ^{16}N spectrum satisfactorily, leaving the pure ^{15}C spectrum.[25]

DEUTERIUM

Deuterium, like ^{15}N, is extensively used in biological studies and is most commonly determined by mass spectrometry or infrared analysis. The determination of deuterium by activation methods will be discussed under the section on hydrology.

Pollution Studies

In the studies of pollution, in both air and water, a stable element rather than a stable isotope has been used in the examples to be cited. The probable reason for this is that the actual quantity or bulk of material to be traced is so great that the cost of a stable isotope for such tests would be prohibitive. Tracing with an element not commonly found in the particular environment under study and its subsequent determination by activation analysis appears to be satisfactory and gives useful results.

AIR-POLLUTION STUDIES

Haines, Hemeon, and Cember[26] have tracked the ground-level distribution of stack-gas emissions using antimony as an activable tracer. The requirements for such a tracer technique include effective collection with a filter-paper sampler, safety in that the tracer must be nontoxic and nonperceptible to persons in the concentrations that would occur at ground level, absence of the tracer as a normal constituent of the atmosphere, and provision of a stable dispersion in the atmosphere. Antimony oxide was selected as the tracer substance because it was normally not present in significant concentrations in the atmosphere and because it had a suitable cross section and sufficiently energetic radiations, principally from ^{122}Sb, for easy detection by neutron activation analysis.

Antimony oxide powder was injected into the stack-gas stream or the atmosphere at some appropriate location. (The degree of dispersion was determined by passing a fraction of the dispersed aerosol through a specially designed sedimentation channel.) Several automatic ground-level samplers at selected locations were placed in operation well in advance of the sample run (for background readings). The samplers automatically advanced a strip of filter paper from the supply roll at predetermined intervals, usually 1 to 2 hr. In the laboratory the filter-paper samples were cut, labeled, and packaged and were then irradiated for 1 week at Oak Ridge National Laboratory. Upon return to the laboratory, the samples were processed for separation of soot and other extraneous pollutants deposited on the filter paper. The activity of the precipitated antimony was determined with a Geiger counter, and, by comparison with known quantities of antimony as standards in the irradiation procedure, the amount of antimony present was determined. The sensitivity of the method permits the measurement of less than 0.01 μg, with an accuracy of 0.003 μg.

Tarras and Pirtle[27] (Tracerlab), in cooperation with the Public Works Department, Ventura County, Calif., undertook an application of the stable-tracer activation-analysis technique for determining industrial fallout on a commercial basis, especially the contribution to the fallout problem from a specific aggregate-processing plant in a naturally dusty, heavily industrialized environment. Industrial dusts were collected at ground level for some known time as background samples. Then 100 g of each tracer element was mixed with the raw materials entering the process at the plant, and again samples were collected at the same station for the same length of time as the background samples. Samarium, holmium, and silver were chosen as tracer elements because of their suitable cross sections, availabilities, low occurrences in materials under study, characteristic radiations, and half-lives of their isotopes. After irradiation at a flux of 5×10^{13} n/(cm^2)(sec) for 4 days, the minimum detectable amount of the tracer was about 10^{-14} g. From the estimated fraction of raw material emitted in the stack effluent, the fallout area under consideration, and the assumption that 25% of the stack effluent appears as fallout dust in the area under consideration, the quantity of tracer per square foot should be 1.47×10^{-11} g. The sensitivity of the application is therefore greater than necessary by 2 to 3 orders of magnitude.

In elaborating on this same work, Wright[28] (also of Tracerlab) states that a maximum of 2.15% of the dustfall in the area under study was contributed by the industrial plant. The less-sensitive silver tracer, run at different times, gave results that showed a maximum contribution of about 6%.

The previous studies were concerned with particulate fallout, but of more general interest is the use of stable tracers for following gaseous effluents

in both small- (individual plants) and large-scale studies. Techniques are available for generating stable, uniform, and small-size aerosols of most inorganic species. Any aerosol of any of the stable elements listed by Wright (Pd, Cd, In, Sb, Sm, Eu, Tb, Ho, Tm, Lu, Au) with a particle size of less than 0.3 μ would behave essentially as a gas. Collection of air particulate samples of this size range throughout the volume of air surrounding such a generator and analyzing these samples by neutron activation permit unequivocal information to be established as to the interaction of the gaseous effluent from the stack with the normal environment; such a study would provide effluent-distribution information in both space and time. A study based on this technique has been proposed by Tracerlab to determine the amount of ventilation available in the San Francisco Bay area. Detailed technical discussion of the proposal was given.

The application of neutron activation analysis without troublesome chemical processing to stack-gas tracing has been tried by Nakasa and Ohno[29] using powdered cobalt sulfate as a tracer substance. Field tests have shown the technique to be useful for observing the atmospheric diffusion characteristics of the stack gas in the industrial area. Cobalt has several advantages for such tracing—normal cobalt is 100% ^{59}Co; the cross section is large (37 barns); the half-life of the induced radioactive isotope is long (5.26 years), which allows decay of interfering radionuclides of short half-life; and the sensitivity of the determination increases with higher fluxes and longer irradiations. Cobalt-60, with its 1.17- and 1.33-Mev photopeaks, has a 2.50-Mev sum-peak, and by this peak it can be identified quantitatively without chemical separation of the ^{60}Co from other radionuclides of long half-lives. In addition, cobalt behaves similarly to stack gas in the atmospheric diffusion process, is easily dispersed at a measured rate in the atmosphere, and is nontoxic and inexpensive. Spraying of a water solution of cobalt sulfate into a stack-gas stream with atomizers produced finely divided particles—mean diameter, 3 μ—of cobalt sulfate powder. These were discharged with the effluent gas into the atmosphere and were expected to have the same behavior as the gas without an increase in the particle size by adsorption of moisture. Samples were collected on filter paper in high-volume dust samplers at several locations. The filter-paper samples were irradiated in a thermal-neutron flux of 1.7×10^{12} n/(cm^2)(sec) for 15 hr. After the samples had cooled for 3 weeks, their activities were measured with a 3- by 3-in. NaI(Tl) scintillation well counter and a multichannel pulse-height analyzer. There were many photopeaks, and the 1.17- and 1.33-Mev photopeaks of ^{60}Co were masked by those of ^{46}Sc, ^{65}Zn, and ^{59}Fe. However, the 2.50-Mev sum-peak of ^{60}Co was not subject to interference by peaks of these nuclides, and the ^{60}Co could be quantitatively identified by this sum-peak. With this method 5×10^{-8} g of cobalt can be determined with an accuracy of 10%. Some results of field tests were also given.

STREAM-POLLUTION STUDIES

Chatters and Peterson[30] have applied a stable-tracer activation-analysis technique to obtain a better understanding of the sources of stream pollution originating in the pulp and paper industry as well as to assist in the decrease of these sources of pollution by means of in-plant process control. Their method involved tagging the fibers with metallic salts in such a manner as to cause the metallic component either to become bonded with the cellulose or to be precipitated within the fiber lumen. After removal of excess additive, the tagged fiber can be introduced at any desired point in the mill for subsequent collection of fiber samples at various points downstream in the process line. The samples can be irradiated in a reactor, at any convenient time after collection, for activation of the additive and the radioactivity subsequently determined with a 400-channel analyzer. Lanthanum meets the requirements of a good tag for pulp because it adheres to the fibers throughout the chemical and physical environment of the mill process lines and its activation product, ^{140}La, from the activation of the 99.91% abundant ^{139}La by the ^{139}La$(n,\gamma)^{140}$La reaction, has gamma radiations that are detectable even in low tracer concentrations in the presence of activated elements normally present in the pulp fibers and has a half-life long enough to allow decay of short-half-life impurities (^{56}Mn and ^{38}Cl). In addition, lanthanum is not a normal constituent of wood. Silver also meets the requirements, but it is too expensive for repeated large-scale mill runs. Furthermore, measurement and detection sensitivities were not great enough unless long irradiations were used. Results of in-plant tests in two different types of paper mills showed that lanthanum-treated fibers were quantitatively detectable in the presence of the greater mass of untreated wood fibers at all points along the process lines where samples were obtained. These tests also indicated that the various chemical and physical environments found in the paper mills had no deleterious effects on the lanthanum-treated pulp and that dilution ratios of 3 lb of treated pulp to 40 thousand pounds of untreated pulp could be effectively used in following the fibers through the mill. All experiments were conducted without interrupting or interfering in any way with normal operating procedures.

(Part II will follow in a subsequent issue.)

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Measurement of Ventilation Rates with Radioactive Tracers

By Martha Gerrard

Abstract: The published literature indicates that the nuclides most used for studying ventilation rates are the radioisotopes of the noble gases. Of these, 10.8-year ^{85}Kr is the most convenient because it can be stored until needed.

The need for adequate ventilation of buildings is well understood by both builders and laymen, and ventilation requirements are taken into consideration in designing heating systems. Nonradioactive tracer methods of measuring ventilation rates, which have been in use for more than a century, were reviewed by Collins and Smith[1] in 1955. Substances that have been used for this purpose include carbon dioxide exhaled by the occupants of a room, water vapor, tertiary butyl hypochlorite, hydrogen, and helium. In addition to the disadvantages of sampling and analysis necessitated by all the chemical tracers, specific problems are offered by some of them—e.g., hydrogen may create an explosion hazard, water vapor is absorbed by walls and furnishings, and butyl hypochlorite does not give consistent results. The use of radioactive isotopes as tracers eliminates the need for taking samples since the tracer can be measured in situ by counting the radioactivity emitted by it. Data are obtained immediately, the record of results may be made continuously, and both accuracy and sensitivity are high. Several reviews on the use of radioactive tracers in ventilation studies have been published.[2]

Method

The radioisotope-tracer method for determining the ventilation rate of an enclosed space consists, basically, in introducing a radioactive substance into the space, mixing the tracer homogeneously with the air in the space, and determining the decrease in tracer concentration with time. Of course, if the half-life of the radioisotope is short compared with the time interval over which measurements are made, corrections for decay must be made.

The ventilation rate, R, is calculated from the data obtained in the test, using the relation

$$R = \frac{1}{t - t_0} \ln \frac{C_0}{C_t}$$

where C_t is the tracer concentration determined by the instruments at time t, a finite time after the tracer has been mixed with the air, and C_0 is the concentration immediately after mixing, i.e., at time t_0. This relation is derived from

$$C = -\frac{V_0}{Q}\frac{dC_t}{dt} = C_0 e^{-Q(t-t_0)/V_0} = C_0 e^{-R(t-t_0)}$$

where Q is the volume of air introduced per unit time and V_0 the total volume of the enclosed space, so that $R = Q/V_0$.

CHOICE OF RADIOISOTOPE

A radioactive tracer suitable for measuring ventilation rates must have a half-life long enough for measurements to be made conveniently but short enough that there will be no long-term aftereffects. There must be no harmful decay products. The energy of the radiation should be high enough that detection with existing instrumentation is possible, and the amount of radioactive material required should be small enough that there will be no hazard to persons involved.

The radioisotopes most suitable for ventilation tests are those of the chemically and biologically inert noble gases:

Nuclide	Radiation energy, Mev		Half-life
	Beta	Gamma	
^{133}Xe	0.35	0.08	5.3 days
^{85}Kr	0.67	0.52	10.8 years
^{41}Ar	1.20	1.29	1.83 hr

Krypton-85 is the most convenient to use because of its 10.8-year half-life—it can be obtained from a supplier and stored until tests are to be made. Xenon-133 and ^{41}Ar must be obtained immediately before use. However, all three have been used in ventilation tests.

Radon and thoron are not mentioned here as possible tracers because they are not usually added to an atmosphere intentionally. In places where they are already present, as in a uranium mine, their decay products, which are solid and which collect on filters in the mines, have been determined[3] to show whether the mine is being ventilated sufficiently. However, the determination of such solid products is difficult, and every attempt should be made to keep the concentration of these gases as low as possible in a mine.[4]

Radioactive isotopes of some other elements have been used. For example, ^{82}Br was being used[5] in England as early as 1950 and has been reported used[6] in the form of methyl bromide for studying airborne dusts in a coal mine and a tunnel. However, a radionuclide-labeled chemical tracer has many of the same disadvantages as nonradioactive chemical tracers. Labeled methyl bromide, for example, is absorbed on walls,[1] and labeled (^{14}C) carbon dioxide dissolves readily in any moisture present.[7] Either ^{14}C- or ^{3}H-labeled methane is of interest for studying removal of methane from coal mines.[8]

Specific Tests

Early studies using radioisotope tracers to determine ventilation rates in rooms were made in both France and England. Gueron[9a] (and Cadiergues) reported at the Oxford conference in 1951 on air-change measurements made in a very leaky laboratory with ^{133}Xe. An unknown amount of xenon was mixed with the laboratory atmosphere by means of a fan, which was operated for 5 min. After the fan was stopped, the radioactivity was measured continuously for 35 min, using an ionization chamber. The decrease in activity with time followed a first-order law, with a clearly marked irregularity at the time that fume hood fans were turned on. (The work was subsequently reported in journals.[10]) Also at the Oxford conference, Seligman[9b] reported on the determination of air-exchange rates with ^{41}Ar. He stated that the measurements would have been difficult and cumbersome by any other method.

Collins and Smith[1] successfully used ^{41}Ar to measure the ventilation rate in a specially constructed experimental house, after unsuccessfully trying to use $C_2H_5{}^{82}Br$. Howland, Kimber, and Littlejohn[11] used ^{85}Kr to determine the rate of air change in a typical two-story detached house with a volume of about 7 thousand cu ft. The technique showed considerable sensitivity and flexibility. The rapid response of the detectors gave the method a great advantage over chemical-tracer methods, since the immediate effects of changing conditions—e.g., closing bedroom doors or opening windows—could be investigated. They suggest that the measurements could not have been made by any of the chemical-tracer techniques.

In homes where gas is used, ventilation problems may be particularly serious. The French gas industry[12] used 5 mc of ^{133}Xe to measure the rate of ventilation in a cross-ventilated room of 8 m^3 volume. Measurements were made easily and precisely both of the overall air exchange with normal ventilation and of inleakage rates with all ventilation cut off. The gamma radiation was measured with a scintillation detector and the beta with a Geiger–Mueller counter.

Although the majority of ventilation tests with radioactive tracers have been reported for domestic dwellings, such tests have also been made on a number of other types of enclosures. In Sweden, for example, 500 mc of ^{85}Kr was used to measure the air flow in a hayloft,[13] and in Germany 10 mc of ^{41}Ar was used to determine the air flow pattern through a hay ventilator.[14] Krypton-85 is useful for studying air currents in a coal mine.[7]

Both ^{85}Kr and ^{133}Xe were used[15] in an investigation of the rates of leakage and of air change in a facility designed to simulate a railway car moving at 0 to 120 km/hr. From the data, factors contributing to heat loss, as well as to the speed and direction of air movement inside the car, were identified. The Australians,[16] in trying to find the point of leakage of CO from the engine of an airplane into the cabin, used ^{85}Kr to trace the flow of air and concluded that the information would have been difficult, if not impossible, to obtain by other methods.

In a metal heat-treating plant, ^{85}Kr was used to determine the minimum purging rate of a furnace.[17] The tracer was injected into the furnace through the purging-gas line, and a continuous stream of gas was drawn out through the thermocouple ports. The exit streams were passed over a scintillation counter to measure the ^{85}Kr removed. Not only was the gas flow inside the furnace determined but also the amount of the original atmosphere remaining after the purge.

The above examples show that the radioactive noble gases are quite useful for determining ventilation rates in various kinds of enclosed spaces. The uses have not been fully exploited, and consideration might well be given to the radioactive-tracer techniques by anyone interested in ventilation problems.

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Portable Radioisotope X-Ray-Fluorescence Analyzer*

Abstract: A portable X-ray-fluorescence analyzer has been developed which consists of a 3-lb probe unit and a 12-lb electronics unit. In tests of the prototype unit, with radioactivity counting times of 10 to 100 sec, sensitivities of determination have ranged from 0.002% for silver in ores to 0.2% for sulfur in coal.

A portable X-ray-fluorescence analyzer could have many applications in mining, geology, metallurgy, and engineering, e.g., assay of ores, cement, and coal; analysis of alloys for identification purposes; quality-control measurements; analysis of scrap for sorting purposes; checking of ingots, sheet, and other forms of stock; and recognition of components after certain manufacturing processes, such as extrusion or forging, which obliterates ordinary markings. The immediate obtaining of results would result in a saving of both time and money.

X-ray-fluorescence spectrometry is well suited to sensitive, nondestructive, and rapid determination of elements because of the ease of exciting and detecting the relatively simple X-ray spectrums that are characteristic of all elements with atomic numbers above about 10. In contrast to machine X-ray sources, radioisotope X-ray sources are small, compact, and inexpensive and require no external power source.

X-ray-fluorescence analytical techniques[1] have been widely studied over the past 10 years and have been refined to a stage where practical instruments are being manufactured. The wide interest in the subject is indicated by the holding of at least two symposiums on low-energy X and gamma sources.[2,3] The instrument described here was developed by Texas Nuclear Corporation under sponsorship of the U. S. Atomic Energy Commission's Division of Isotopes Development. It has reached the prototype stage and has shown high performance and versatility in preliminary tests. Some of the advantages[4] of the final model of the instrument are the simple sample-presentation mechanism; the low noise level of the photomultiplier tube, which makes sulfur determination possible; the high gain–low noise amplifier, which eliminates the need for using a preamplifier with a gas proportional counter; the incorporation of a single-channel analyzer, which provides discriminator versatility; and

*Based on J. R. Rhodes, T. Furuta, and J. D. Hall, X-Ray Analysis Using Radioisotope Sources, USAEC Report ORO-3224-12, Texas Nuclear Corporation, 1967.

the incorporation of a high-speed scaler with reverse mechanism for subtracting background.

Description of the Analyzer

The portable radioisotope X-ray-fluorescence analyzer consists of a 3-lb probe (Fig. 1*a*), which contains the radioisotope source and radiation detector, and a 12-lb electronics unit (Fig. 1*b*). The two are connected by a cable.

The principle of operation of the gage is simple (Fig. 1*c*): The X-radiation from a radioisotope source is allowed to strike the sample being analyzed, and the reflected, or fluoresced, X-radiation, whose wavelength(s) is characteristic of the element(s) in the sample, is determined. The radiation source may be a radioisotope that emits X rays, e.g., ^{55}Fe, or a beta emitter plus a target element in which a secondary radiation—X rays—is produced by the impinging beta particles. An example of this type of X-ray source is $^{3}H/Ti$. The radioisotope sources considered in this program are discussed in the "Applications" section below.

PROBE

The relation of the source to the detector and the auxiliary components is shown in Fig. 1*d*. The source is deposited as a thin film on a 5-mm-thick gold, tungsten-alloy, or brass disk, so that useful emission is from one face only. The active area is about 5 mm in diameter, and the overall area is about 1 mm in diameter. Radiation from the source reaches the sample through a 1.8-in.-diameter aperture, which is closed by a shutter when not in use.

The shutter contains a 0.5-in.-diameter by 0.06-in.-thick tungsten-alloy shield, which attenuates by a factor of 10^5 the low-energy X-radiation from the sources used. The shutter is opened by depressing a projection, or "foot," on the face of the probe, and it springs back automatically to cover the source when the pressure on the foot is released. With a large sample the probe may be held in the hand (Fig. 2*a*). A small sample may be placed on the face of the inverted probe and covered with a shielding cap that is heavy enough to depress the shutter-operating projection (Fig. 2*b*). The size of the aperture is not decreased for use with smaller samples because of the decreased sensitivity that would result from decreased intensity of the fluorescent ray and increased scattering from the underside of the aperture plate. For example, the sensitivity is decreased by a factor of 2 when the aperture is decreased to 1 in. in diameter.

The measuring head is designed to place the sample at an optimum distance from the source, i.e., where the maximum radiation will be detected. This distance is set by three projections on the face of the probe—the shutter-operating foot, which extends

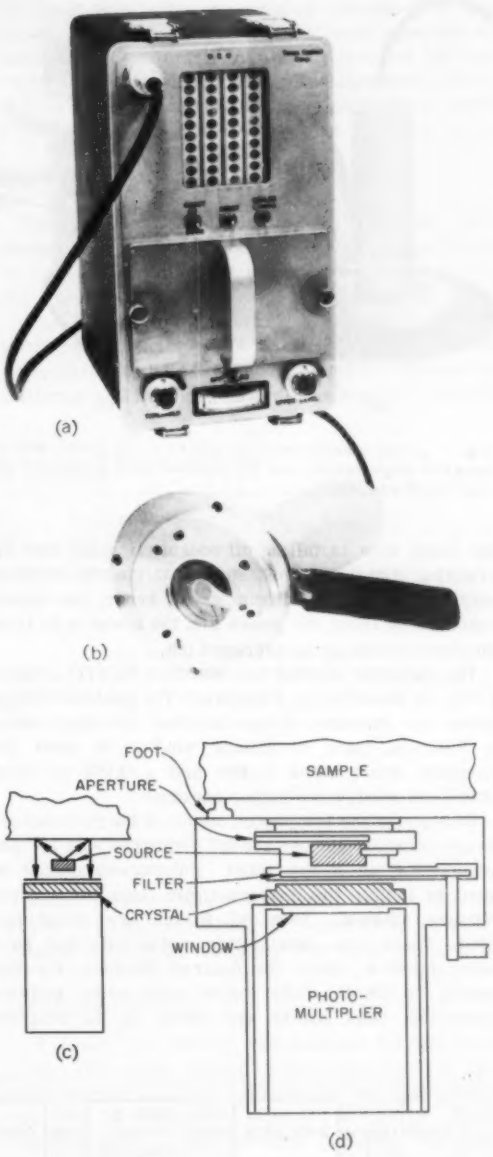

Fig. 1 Portable radioisotope X-ray-fluorescence analyzer: (a) electronics unit, (b) probe, (c) principle of fluorescence measurement, and (d) diagram of probe construction.

0.1 in. from the surface when pressed down, and two 0.1-in.-long nondepressible feet. This length was chosen because the sample may be moved 0.05 in. away from the probe face with less than 1% change in the detector count rate, and, at a distance of 0.1 in.,

(a) (b)

Fig. 2 X-ray-fluorescence analyzer. (a) probe held in hand for large sample and (b) inverted, with a cap, for use with small sample.

the count rate is falling off roughly linearly with increasing distance. Thus somewhat uneven surfaces may be measured without great error, the higher count rates from the peaks and the lower ones from the depressions being averaged out.

The detector crystal is a standard NaI(Tl) crystal, 1.5 in. in diameter by 2 mm thick. The photomultiplier tubes are standard 2-in.-diameter 10-stage tubes. A 0.005-in.-thick beryllium window is used for energies below about 8 kev and a 0.001-in.-thick aluminum window for higher energies.

Because of the low photon output of the radioisotope X-ray sources (10^7 per second compared with 10^{13} per second for an X-ray tube), collimators cannot be used to isolate the characteristic lines for a given element. Instead, balanced filters are sometimes used. These are usually thin metal foils that have been etched to obtain the desired thickness for balancing or plastic foils loaded with some suitable compound. Only filters are shown in the diagram given here, although other methods of resolution were used in some of the tests on the instrument (see "Applications" section below). However, if the exciting energy from the source can be chosen so that the detector resolves the backscattered X rays from the desired fluorescence rays, balanced filters are not needed, and the addition of a pulse-height analyzer is justified. Sometimes even a NaI(Tl) scintillation counter provides sufficient resolution, and good Ge(Li) or Si(Li) solid-state detectors might be used.

ELECTRONICS UNIT

The electronics unit (Figs. 1*b* and 3) is housed in a $5^{11}/_{16}$- by 7- by 10-in. aluminum box. The control panel forms a weathertight closure for the unit and supports all electronic components. The unit is removed from the housing by simply opening four luggage fasteners and lifting out the working parts. Access to the batteries is through the control panel so that the components remain isolated from the environment during battery change.

The unit will operate about 50 hr from 10 D-size flashlight batteries. A 110-volt a-c line may be used when available, or alkaline or mercury cells may be used under low-temperature conditions or for longer life.

Applications

Only a few feasibility studies have been made with the portable radioisotope X-ray-fluorescence analyzer, and these are not representative of the whole range of potential applications. However, they illustrate the capabilities of the instrument.

SULFUR AND ASH IN COAL

Sulfur, which occurs in coal in both organic and inorganic form and is present in amounts up to 5%, is a potential air pollutant. The combustible part of coal is mainly carbon, hydrogen, and oxygen. The mineral matter in coal contains significant concen-

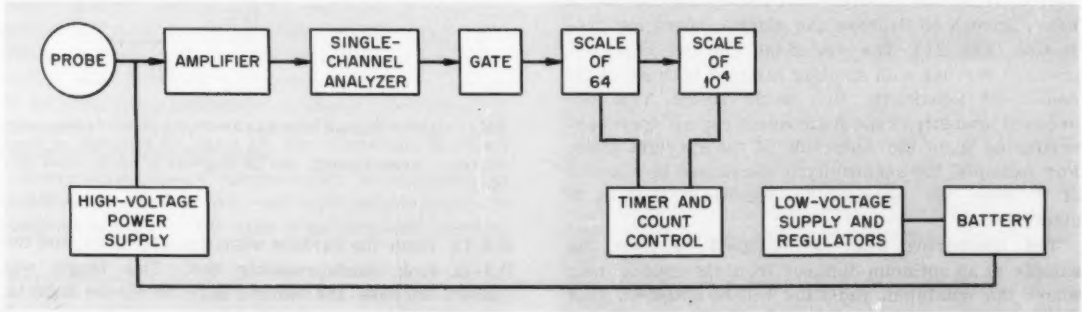

Fig. 3 Block diagram of electronics unit.

trations of Al, Si, Ca, and Fe besides S, so that "ash" consists mainly of aluminosilicates, iron oxide, and some calcium oxide. The ash content of coal should be known prior to burning in order that the combustion efficiency may be determined.

Fluorescence excitation of the sulfur K X-radiation (2.31 kev) is being considered for sulfur determination and measurement of the total backscattered X-ray intensity (excluding the fluorescence X rays) for total ash determination.

Sulfur. Measurements of the sulfur content of synthetic coal samples were made with a standard deviation of 0.17% sulfur when a 3.5-curie $^{3}H/Ti$ source was used with a single-channel pulse-height analyzer and balanced filters (Table 1). There was no interference from the ash. Sensitivity was poor with a ^{55}Fe source.

Table 1 SENSITIVITY IN DETERMINATION OF SULFUR IN SYNTHETIC COAL WITH FLUORESCENT X-RADIATION

Source	Resolution method	Count rate, counts/sec		Standard deviation in 100-sec counts, % S	Remarks
		Per 1% S at 5% S	At 0% S with each filter		
$^{3}H/Ti$, 3.5 curies	Pulse-height analyzer, balanced filters	15	370; 350	0.17	
	Pulse-height analyzer only	10	950	0.3	Severe interference from Ca K X rays
	Balanced filters only	14	3530; 3520	0.6	Poor counting statistics
^{55}Fe, 1 mc	Pulse-height analyzer, balanced filters	0.4 to 1	125; 110	2.5	Source activity of at least 10 mc required

Ash. With a 1.6-curie ^{109}Cd source, ash contents of 5 to 15% in the synthetic coal were determined by counting the backscattered X-radiation and correcting for sulfur (2 and 5.25%). Errors were within ±0.27% when the sulfur was known to ±0.2%. A 4-curie $^{3}H/Zr$ source gave similar results. With a $^{3}H/Ti$ source, precision was slightly lower and with ^{55}Fe, much lower.

CALCIUM OXIDE AND IRON OXIDE IN CEMENT RAW MIX

Cement raw mix contains about 44% CaO (as calcium carbonate) and 1 to 5% Fe_2O_3.

CaO. With a 1-mc ^{55}Fe source, calcium in synthetic mixes was determined from the fluorescent X rays with no interference from iron present. With 45% CaO contents, the standard deviation in a 50-sec count was equivalent to 0.1% CaO. With a $^{3}H/Zr$ source, correlation of CaO measurements with the known contents was excellent.

Fe_2O_3. With a 4-curie $^{3}H/Zr$ source and a 0.0005-in.-thick iron filter to remove calcium K X rays, correlation with the known iron oxide contents was excellent and interference due to variable CaO concentrations was insignificant. The standard deviation due to counting statistics was equivalent to 0.045% Fe_2O_3 at 3% Fe_2O_3 in a 50-sec count.

COPPER IN COPPER ORES

The copper content of ores of economic grade ranges upward from about 0.2%. Some 0.5 to 7% iron is usually present, and occasionally there is up to 2% cobalt.

The copper in synthetic ore samples containing 2.0% copper, 2.1 to 7.0% iron, and 2.0% cobalt was determined with a ^{109}Cd source, using a pulse-height analyzer and balanced filters. The standard deviation at zero copper content was 0.03% copper with count times of 20 sec per filter. This sensitivity is entirely adequate for assay of copper ores of economic grade.

GOLD IN GOLD ORES

A 1-mc ^{57}Co source was selected for determining gold. The main energy of this source—122 kev—excites gold K X rays efficiently and is higher than the gold K absorption edge (80 kev). The Compton backscattered energy (83 kev) is partly resolved by the NaI(Tl) scintillation counter from gold K X rays (67 kev), and suitable balanced filters separate out various interferences. With a count time of 30 sec, the standard deviation was 0.03% gold.

A ^{153}Gd source compared favorably with ^{57}Co as a radiation source.

SILVER IN SILVER ORES

Both synthetic and natural silver ores were studied. Among the sources tested for use in determining

silver were ^{241}Am, ^{153}Gd, and ^{147}Pm/Al. A number of possibilities, including the use of a solid-state detector, were investigated, with encouraging results.

(MG)

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Eggshell-Strength Determination by a Beta-Backscatter Technique

Abstract: A nondestructive method has been developed for determining eggshell strength by measuring the beta radiation backscattered from it. A 10-μc ^{106}Ru–^{106}Rh source provides the beta radiation.

The increased use of mechanical handling of eggs during the past few years has resulted in increased loss due to shell breakage—a loss that reached $25 million in 1965. Shell quality, which depends on such factors as age, diet, and production rate of the hen, has not improved as much as is required by the mechanization of egg handling, and methods for determining shell strength are needed. Some of the methods that have been tried involve measuring the pressure required to break the shell, the deformation on twisting, and the height from which a small weight has to be dropped to crack the shell. Both the time required and the damage to the shell make these methods unsatisfactory. A nuclear method[1–5] for measuring eggshell strength has been developed by R. S. Pressly at Oak Ridge National Laboratory and Paul E. James at the U. S. Department of Agriculture, Beltsville, Md., under a Division of Isotopes Development contract. The method is rapid and does not affect the egg viability or edibility; there is no residual radiation in the egg. The gage has already attracted attention abroad.[6]

Method

The beta-backscatter technique described here does not differentiate between a thin, dense material and a thick, light material but actually measures the density–thickness characteristic of a material. It was therefore not surprising that tests on the gage showed a good correlation of backscatter values with impact-strength values.

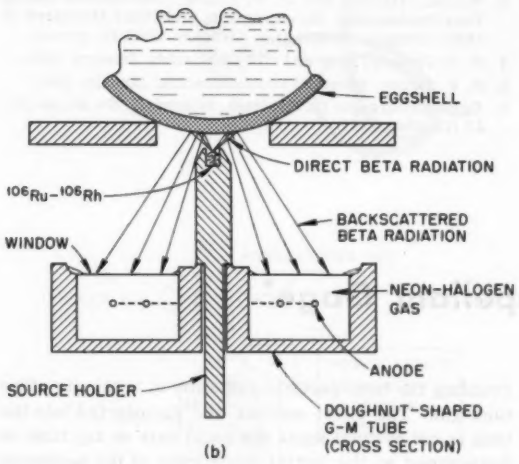
GAGE

The basic components of the eggshell-strength gage (Fig. 1) are the radioisotope source and radiation detector, which are housed in the same aluminum container. The radiation reaches the shell through an aperture in the egg holder, and a cover is provided to shield the radiation source when the gage is not in use.

The radioisotope chosen was ^{106}Ru, since the 10 μc needed for a good count in 5 sec can be used without the need for a specific AEC license. Its daughter, ^{106}Rh, emits a 3-Mev beta particle, which is sufficiently energetic to penetrate and return from eggshells of the maximum thickness encountered. The chief disadvantage of this radioisotope is its short half-life—1 year—which necessitates replacement after about a year. Strontium-90, which is available in high specific activity, requires less shielding, and has a 28-year half-life, could be used. However, only 1 μc of ^{90}Sr can be used with a general license. The radiation from this amount of material is not sufficient to give a good statistical count in 5 sec, and a long counting time would make the test too slow for commercial use.

The source was formed by incorporating the radioisotope in a matrix. Cylindrical pellets, 1 mm in diameter by 1 mm long, were pressed from Molecular Sieve material (Al_2O_3–Na_2SiO_3) and were soaked in a 0.01*M* HCl solution of ^{106}Ru to allow the ruthenium to exchange with the sodium. The pellets were then heated to 1100°C to form a ceramic, which is the first containment medium for the radioactive material. The fusion did not destroy the cylindrical shape of the pellets but did decrease the volume about 20%. A number of the pellets were then placed in a cavity in the end of a tungsten rod, and the cavity was

(a)



(b)

Fig. 1 (a) Photograph and (b) diagram of radioisotopic eggshell thickness gage.

sealed and covered with a thin epoxy resin film—the second containment medium. (Work is currently under way on concentrating the activity in a single pellet.) This method of mounting the source provides collimation and directs the beta particles toward a small area of the shell, thus decreasing the effect of shell curvature. Also, it decreases the amount of direct beta and gamma radiation reaching the detector.

The backscattered-radiation detector is a doughnut-shaped Geiger–Mueller tube; the source holder is placed in the hole of the doughnut. The egg rests above the source on a support, which is mounted on sponge rubber so that it will be easily depressed when the egg is placed in position for testing. The egg is placed with the long axis horizontal, i.e., so that measurements are made at the "waist" (half way between the poles) of the egg. The optimum distance from the source to the shell was found to be 0.075 in. when the source was 0.75 in. above the window of the detector. A 0.75-in.-diameter aperture above the source was found to be satisfactory.

CORRELATION OF GAGE MEASUREMENTS WITH SHELL STRENGTH

Although more research is needed to determine exactly what eggshell quality is being measured by the gage, preliminary tests showed a good correlation between gage readings and strength (Fig. 2). Correlation with strength values was better than with thickness values determined with a micrometer.

There are no standard methods of measuring impact resistance, and a method was devised which involved dropping a 0.7-g steel ball, $^{7}/_{32}$ in. in diameter, from increasing heights until the egg fractured. In the early tests as many as 10 drops were required before the shell fractured, and this was thought to have a weakening effect on the egg before it actually broke. In subsequent tests the required height was estimated from the backscatter data, and then only two or three drops were required.

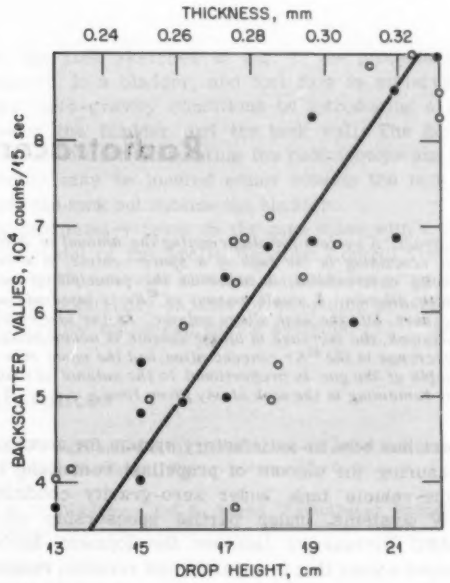


Fig. 2 Correlation of backscatter-radiation data with (●) height from which ball is dropped to fracture and with (○) thickness.

Tests on Eggs

The gage was sufficiently precise that eggs could be separated into six categories according to shell strength, ranging from those very resistant to breakage to those easily broken. In one test 24 eggs were listed according to shell strength as determined by the radioisotope gage. The eggs were then sent to another laboratory, where the test was repeated on them. Only one egg appeared in different locations on the two lists. This is considered excellent agreement.

In tests on approximately 600 eggs, the impact resistance was found to be uniform around the waist, but that at the waist was different from that at the ends.

Manufacture of Gage

Although work is continuing on the gage, particularly with regard to using a longer lived radioisotope, the following companies have agreed to manufacture the gage:

Tracerlab
Waltham, Mass. 02154

Nuclear Measurements Corporation
2460 N. Arlington Avenue
Indianapolis, Ind. 46218

Unit Process Assemblies, Inc.
53-15 37th Avenue
Woodside, N. Y. 11377

As with other such devices, each gage must be calibrated by the user within the range of strengths encountered. (MG)

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Radiotracer Propellant Gage*

Abstract: A system for determining the amount of propellant remaining in the tank of a space vehicle, in a zero-gravity environment, is based on the principle of radiotracer dilution. A small amount of ^{85}Kr is injected, under pressure, into the tank ullage volume. As the propellant is consumed, the increase in ullage volume is accompanied by a decrease in the ^{85}Kr concentration, and the count rate of a sample of the gas is proportional to the volume of propellant remaining in the tank at any given time.

There has been no satisfactory system for accurately measuring the amount of propellant remaining in a space-vehicle tank under zero-gravity conditions. TRW Systems, under partial sponsorship of the USAEC Division of Isotopes Development, has developed a gage that is accurate and reliable, responds rapidly, and conforms to power and weight limitations of spacecraft. Preliminary descriptions of the gage have been published earlier.[1,2]

The gage (Fig. 1) is based on the principle of radiotracer dilution. A small amount of ^{85}Kr is injected into the propellant-tank ullage space. As the fuel is expelled from the tank during vehicle propulsion, the ullage volume increases, resulting in a decrease in the tracer concentration in the tank space. The ^{85}Kr concentration, and hence the amount of propellant remaining, is continuously monitored by counting the beta-particle radiation in a sample of the tank gas. The exact amount of ^{85}Kr injected into the tank is not critical since the count rate at any time is normalized to the initial count rate at the beginning of the vehicle mission.

The volume of propellant at any time, V_t, is related to the count rate at that time, C_t, by

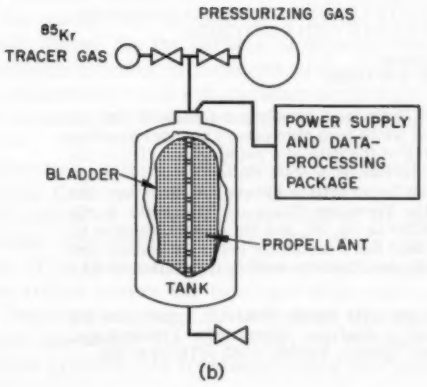
$$V_t = \frac{V_0(C_t - C_0X)}{C_t(1 - X)}$$

where V_0 and C_0 are the initial propellant volume and count rate, respectively, and X is the initial ullage fraction. The counts are fed into a data processor, where they are converted to tracer concentration, which is a function of the fraction of propellant remaining (Fig. 2). If there is a propellant-temperature input to the data processor, the output may be propellant mass instead of volume.

The count rate is measured with semiconductor detectors and integrated counting circuitry. Recent improvements in such detectors now permit detecting ^{85}Kr beta particles with high efficiency while providing almost complete insensitivity to all types of external radiation. The use of ^{85}Kr, which is chemically inert, eliminates the possibility of chemical reactions that might introduce errors into a dilution measurement. The fact that this element is not retained in the body is an additional advantage because there is relatively little safety hazard to personnel.

*Based on B. Burns, R. W. Harman, R. J. Rusch, R. B. Spencer, and G. A. Sisk, Exploratory Development of the Radiotracer Propellant Gauge, Final Report–Phase II, USAEC Report TID-23666, TRW Systems, 1966.

(a)



(b)

Fig. 1 (a) External components and (b) diagram showing principle of radiotracer propellant gage.

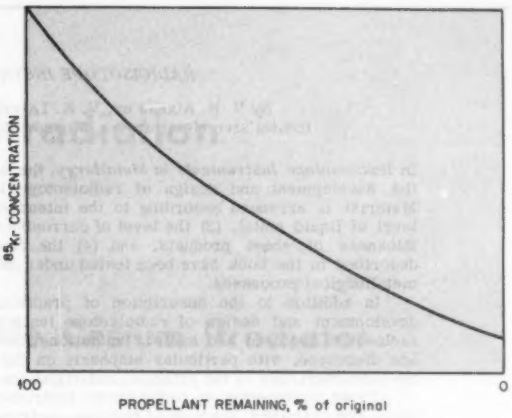


Fig. 2 Tracer concentration as a function of fraction of propellant remaining.

In the tank sketched in Fig. 1, the propellant is contained in a bladder, and fuel flow is maintained under zero-gravity conditions by introducing a gas between the bladder and the tank wall. The fan or other device for circulating the radioisotope and the detector may be located either outside the tank or inside the tank but outside the bladder.

In preliminary tests on the gage made with a full-scale model of the Apollo Reaction Control System, the results indicated that the radiotracer propellant gage is potentially capable of exceeding prescribed accuracy for spacecraft gaging systems. (MG)

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2. J. F. Wakeman and B. Burns, Radiotracer Propellant Gauge, *Instrum. Contr. Syst.*, 40(3): 95-97 (1967).

RADIOISOTOPE INSTRUMENTS IN METALLURGY

By V. N. Afanas'ev, V. K. Latyshev, V. V. Lyndin, and A. K. Felinger
Izdatel'stvo Metallurgiya, Moscow, 1966, 224 pp., 108 references (in Russian)

In *Radioisotope Instruments in Metallurgy*, the authors attempt systematically to present material on the development and design of radioisotope instruments applicable to the metallurgical industry. Material is arranged according to the intended use of the instruments, e.g., measurement of (1) the level of liquid metal, (2) the level of corrosive and free-flowing liquids in process equipment, (3) the thickness of sheet products, and (4) the flow rates of liquids and gases. Most of the instruments described in the book have been tested under industrial conditions and are suitable for general use in metallurgical processes.

In addition to the description of practical instrumentation, considerable space is given to the development and design of radioisotope instruments. The physical principles involved in the use of radioactive isotopes and nuclear radiations for monitoring various phases of technological processes are discussed, with particular emphasis on the problem of interactions of radiation with matter and the characteristics of the principal industrial sources of radiation.

Those components of radioisotope instruments which determine their basic operating characteristics are examined. Methods of reducing instrument errors by special systems of radiation measurement are described. New applications and new instruments can be developed from the basic information presented by the authors.

In a concluding section the problems of radiation safety are dealt with. Illustrative problems demonstrate methods and requirements for shielding.

Most of the literature references are to the Russian literature and may not be accessible to many readers. (FJM)

RADIOISOTOPIC DATING OF PAINTINGS: ANALYSIS OF WHITE LEAD FROM THE PAINTINGS OF DUTCH AND VENETIAN MASTERS OF THE 16TH AND 17TH CENTURIES

By F. Lux and L. Braunstein
Angew. Chem. Int. Ed. Engl., 5: 679 (1966)

Lux and Braunstein, following up the work of Houtman and Turkstra,* have begun a study of the use of activation analysis for determining the trace components of white lead pigments. The determination of the trace-element composition may make possible the fixing of the date of a painting and also of the school to which the painting belongs. The Dörner Institute of the Bavarian State Collection of Paintings has made available to the investigators paintings by the Dutch artists Rubens and Vermeer; the mannerists Hemessen, Janssens, and Roymerswaele; and the Venetians Titian and Tintoretto. Early results have shown that Dutch and Venetian white leads differ in Ag, Sb, and Mn content. Studies by both teams of investigators have shown that modern white lead has a distinctly lower Cu content and sometimes a very marked occurrence of a single trace element, thereby making it possible to distinguish imitations from old material.

*J. P. W. Houtman and J. Turkstra, Neutron Activation Analysis and Its Possible Application for Age Determination of Paintings, in *Radiochemical Methods of Analysis*, Symposium Proceedings, Salzburg, 1964, Vol. I, pp. 85-103, International Atomic Energy Agency, Vienna, 1965 (STI/PUB/88).

Section

II

Isotopes and Radiation Technology

Food Irradiation

The Tour of the Portable Cesium Irradiator

Abstract: The tour of the portable cesium irradiator from Arlington, Mass., on Aug. 11 to Seattle, Wash., on Nov. 30, 1967, is described. Products irradiated included potatoes, onions, tomatoes, bananas, oranges, pepper seed, holly, and mushrooms. Over 30 thousand lb of products were irradiated in this period.

The portable cesium irradiator (PCI) was developed by the USAEC to be used in a 2-year tour of the United States for the purpose of demonstrating the irradiation process to members of the food industry and acquainting them with radiation technology. They will evaluate for themselves the results of the irradiation. The PCI (Fig. 1) was designed by Vitro Engineering Corp. of New York and built by American Nuclear Corp. of Oak Ridge. The source, 170 thousand curies of ^{137}Cs, was installed at Brookhaven National Laboratory. The irradiator is operated (Fig. 2) by Isotopes, Inc., of Westwood, N. J. (Fig. 3). This article covers the first part of the tour—from its beginning on Aug. 11, 1967, until the unit completed operations for 1967. Over 30 thousand lb of various products was irradiated during this period.

August

The first stop[1a] of the PCI was at New England Farms Packing Company, Arlington, Mass., on August 11. Products irradiated were tomatoes, bananas, oranges, and potatoes. The stay at New England Farms was the longest of the tour since initial dosimetry qualifications had to be established for the products. A press conference held on August 17 resulted in stories on the news programs of two television stations and one radio station; two local newspapers ran articles and pictures. Later during the stay, tomato and pepper seeds were irradiated.

September

The PCI then moved to Grocery Store Products Company, West Chester, Pa., on September 12. The product to be irradiated was mushrooms.[1b] During the 12-day stop, four other Pennsylvania companies also irradiated mushrooms: J. B. Swayne & Son, Inc., Kennett Square; The Ebbeckes, Inc., Toughkenamon; Brandywine Mushroom Co., West Chester; and DiGiorgio Mushroom Corp., Temple. In all, 752 lb of mushrooms was irradiated. The third stop of the PCI was at K. T. Salem, Inc., Akron, Ohio. About 9 thousand lb of potatoes was irradiated to inhibit sprouting; the average dose was about 10 krads.

October

By September 30 the unit had reached Caruso–Cerisi, Inc., Cincinnati, Ohio. Test runs[1c] commenced on October 2 and included 30 lb of oranges, 130 lb of potatoes, 16 lb of strawberries, and 106 lb of tomatoes. The significance of the Cincinnati stop was reduced by the last-minute decision of Hussman Potato Products and Kroger not to participate in the irradiation demonstrations.

There were three stops in Nebraska: Kitty Clover Division of Fairmont Foods, Omaha; State Capitol Building, Lincoln; and the University of Nebraska, Lincoln. One thousand lb of potatoes was irradiated in Omaha, and an unscheduled press conference there resulted in excellent television and newspaper coverage. On October 11 a press conference with Governor Tiemann and other state officials was held in Lincoln; during the discussion period that followed, irradiated bacon and shrimp were served. Afterward, 850 lb of potatoes was irradiated for Weaver Potato Chips in a demonstration of the operation of the ^{137}Cs unit. Then the PCI was moved across town to the University, where other products were handled for various university groups.

On October 15 the unit arrived at the Fairgrounds in Walla Walla, Wash., for a 4-day stay. The next day 1700 lb of potatoes was irradiated at 10 krads and loaded into 4-lb sacks supplied by the state of Washington. On October 17 the gift sacks[2] were distributed at the opening ceremony. Irradiated ash trays were also distributed. During this stop, 6 lb of

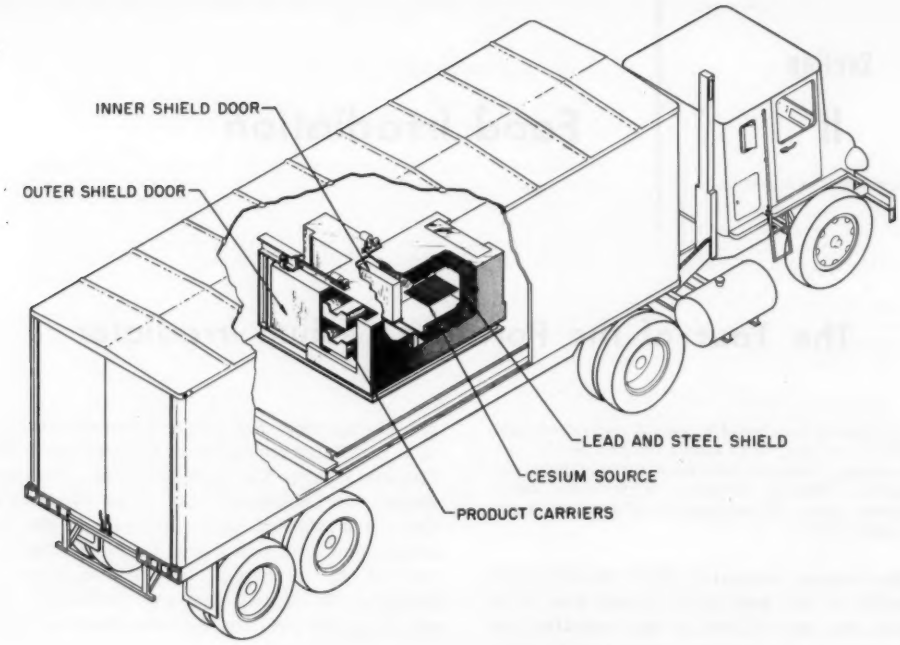

Fig. 1 A schematic of the portable cesium irradiator.

Fig. 2 Typical operation of the portable cesium irradiator.

fresh holly was irradiated for G. R. Kirk Co., Puyallup, Wash. (The PCI was scheduled to stop there in January 1968). Also, 130 lb of flour was treated as part of a disinfestation test for the Washington milling industry. Visitors at the PCI site numbered about 200.

From Walla Walla, the PCI moved to Kennewick, Wash., where on October 23 a ceremony was held at the Benton–Franklin County Fairgrounds to celebrate its arrival. The product to be irradiated here was potatoes. Of the 5700 lb processed, 600 lb was sent by airfreight to Chicago to be served at the banquet of the American Nuclear Society's (ANS) annual convention, 100 lb was given to the Richland chapter of the ANS to be served at their November dinner meeting, and 500 lb was packaged in gift sacks and distributed to members of the Washington State Legislature. The remainder will be used for test shipments to Hawaii and elsewhere.

For the entire period that the PCI spent in the southeastern corner of Washington, good publicity coverage was obtained. In addition, local schools were contacted for showings of the AEC film "Farm Fresh to You" and for tours of the irradiator. In all, 10 articles appeared in the area press before and during the demonstrations; the television and radio coverage was excellent. The film was shown to over 2000 children.

Fig. 3 Collaborators in the building and management of the portable cesium irradiator admire irradiated fruit. Left to right: J. Cusack, Brookhaven National Laboratory; E. S. Josephson, U. S. Army Natick Laboratories; C. B. Wootten, Isotopes, Inc.; G. R. Dietz, USAEC Division of Isotopes Development; A. Brynjofsson, U. S. Army Natick Laboratories; F. T. Richardson, USAEC New York Operations Office; and Lester Sine, Isotopes, Inc. (chief operator of the PCI).

November

The next stop for the unit[1d] was at Big Bend Community College, Moses Lake, Wash. A total of 9100 lb of potatoes was irradiated—700 lb for local storage tests and 8400 lb for the Washington State program. On November 6 the PCI located at Palouse Fair Grounds, Colfax, Wash., where public demonstrations were held. As usual, potatoes were irradiated and some were distributed to the Fair visitors.

On November 11 the PCI arrived in Spokane. After maintenance and repair the unit was set up at the Industrial Park. The unit was demonstrated to about 500 people, and 1400 lb of potatoes was irradiated and distributed. From Spokane the ^{137}Cs irradiator moved west to Seattle, where three visits were made. At Eyres Transfer Co. 1000 lb of potatoes and 150 lb of onions were processed. At the University of Washington, dosimetry studies were conducted in cooperation with Mr. Om Argawal of Washington State University and Mr. Teeny of the Bureau of Fisheries. Some infested flour was irradiated for Fisher Flour Mills to further demonstrate the PCI.

Consumer Evaluation

A consumer evaluation of irradiated potatoes showed an overall favorable opinion. Eight hundred diners[3] at the joint Atomic Industrial Forum–American Nuclear Society banquet in Chicago on November 8 were served potatoes irradiated in the PCI and were asked to evaluate the taste, odor, color, and texture. Diners returned 209 cards; 6 were discarded because they were obviously filled out by wags, i.e., they were signed Ralph Nader, Gar Badge, etc. The results were:

	Excellent	Good	Same	Not as good
Taste	49 (24.1%)	64 (31.5%)	77 (37.9%)	13 (6.4%)
Odor	21 (10.6%)	53 (26.8%)	118 (59.5%)	6 (3%)
Texture	25 (12.8%)	63 (32.3%)	86 (44.1%)	21 (10.8%)

Color was judged as normal, 174 (86.6%); off-color, 23 (11.4%); and objectionable, 4 (2%).

Remarks on taste included "Similar to French bread" and "Not as distinctive as Idaho Russets." The variety of response on the odor evaluation indicated that the olfactory senses of the diners were quite sophisticated. The opinion on texture was regarded as the most important, since an adverse evaluation of the quality would probably negate any favorable impression of the other three qualities tested. The percentage of diners expressing a negative opinion was slightly larger for texture, indicating that texture does have considerable meaning for consumer acceptance of irradiated potatoes.

The potatoes were served steamed or boiled, which might account for some of the low evaluations since most people prepare them some other way, e.g., baked. Because the method of preparation seemed to affect the outcome of this survey, the Washington State Department of Commerce and Economic Development plans to undertake further surveys serving representative groups with potatoes prepared in different ways.

Future Demonstrations

The PCI was stored for the month of December. It was scheduled to begin operations again in early January. After another 3 months in the state of Washington, the PCI will be moved southward along the Pacific Coast to irradiate spring and summer crops as they become available. Results will be reported in future issues of *Isotopes and Radiation Technology*. (F. E. McKinney)

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   b. Monthly Progress Report No. 15 (September 1967), Nov. 3, 1967.
   c. Monthly Progress Report No. 16 (October 1967), Dec. 1, 1967.
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3. L. B. Bradley, Office of Nuclear Energy Development, State of Washington, unpublished data.

The Pilot-Plant Meat Irradiator: Keynote to Commercial Food Irradiation

By George R. Dietz,* Carl B. Wootten,† Morton S. Silberstein‡ and John Masefield§

Abstract: Construction of the world's first irradiation facility for the sterilization of meat products is scheduled to begin shortly. This project will begin the minute the U. S. Department of Agriculture and Food and Drug Administration give their approvals to radiation-processed ham, based on petitions submitted by the Department of the Army in August 1966. When completed, the 400-kilocurie ^{60}Co facility will be capable of processing up to 3 million lb of sterilized product per year. Ham will constitute the major meat item for initial processing. The Department of Defense has agreed to purchase 300 thousand lb of meat and poultry per year, for each of the first 3 years of operation. Another portion will be introduced into the civilian market. Excess plant capacity will be used to process an irradiated pet food to be introduced on the market. This article recounts the total project from its inception to its present status.

Background

In 1959–1960, the Department of Defense (DOD) tightened the reins on its rather broad food-irradiation program, choosing to limit its efforts to the development of radiation-sterilized meat products, primarily ham, pork, chicken, beef, and other items of special military ration significance. The goal was to produce products which could be held at ambient temperatures for months or even years, yet still be completely acceptable, and offer logistical advantages and, hopefully, cost savings over conventionally processed meats. Concurrently, the Atomic Energy Commission (AEC) agreed to undertake the development of pasteurized, or low-dose-treated, foods such as selected fish and fruits, with the objective of increasing the refrigerated storage life or, in the case of

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§Masefield Irradiation Consultants Ltd.

fruits, reducing spoilage during normal refrigerated shipment and distribution.

Two objectives of the Army's revised program, Food Preservation by Ionizing Energy,[1] were to determine how best to make the transition from laboratory processing to pilot-plant production of irradiated foods and to explore the alternatives for funding. In view of the consistently excellent results in processing meat items, as well as the continued clean bill of health on wholesomeness and public-health safety presented by the Army's Surgeon General, the Army approached the AEC in early 1965 to begin discussions of pilot-plant plans.

During the Mar. 30, 1965, meeting of the Interdepartmental Committee on Radiation Preservation of Food, the need for a pilot-plant irradiator for shelf-stable meat and poultry was discussed. The idea was supported in testimony[2] before the Joint Committee on Atomic Energy, Congress of the United States, June 9–10, 1965.

Several possible alternatives for funding were discussed, from full government funding to cost-sharing with industry. Industry was believed to be sufficiently interested to build such a plant with private funds, provided the armed forces would guarantee to purchase a portion of the throughput of the plant over a period of several years and provided the AEC would offer assistance in facility design and source procurement.

In August 1965, AEC Commissioner James T. Ramey and Assistant Secretary of the Army Willis M. Hawkins met with then Assistant Secretary of Commerce Alexander B. Trowbridge to discuss the establishment of a pilot-plant meat irradiator. They concluded that industry should be encouraged to build and operate such a facility in cooperation with the government. Secretary Trowbridge convened an industry–government conference[3] on Sept. 24, 1965, wherein executives of more than 40 companies and trade associations in the meat, poultry, and radiation industries heard the major objectives of the pilot-plant project outlined. At this time, the government's offer of participation included:

1. Purchase of 150 thousand lb of radiation-sterilized meat annually by the Department of the Army and a probable additional 150 thousand lb per year by the Navy and Air Force.

2. Funding assistance by AEC, to include $140 thousand for engineering-design assistance and $180 thousand for the radiation source.

3. Assistance by the Department of Commerce in private commercialization efforts and also a canvass of other government agencies and institutions in an attempt to raise procurement commitments to a higher level.

Secretary Trowbridge and Mr. Anthony A. Bertsch, Chairman of the Interdepartmental Committee on Radiation Preservation of Food, presented the interests of the Department of Commerce, while Mr. E. E. Fowler, Director, Division of Isotopes Development, and Dr. E. S. Josephson, Associate Director for Food Radiation, U. S. Army Natick Laboratories, were key spokesmen for the AEC and Department of the Army, respectively.

Preliminary cost estimates presented at this time by the AEC suggested that capital costs for a million pounds per year plant would approach $1.3 million; of this amount, up to $320 thousand would be provided by AEC for the radiation source and for design assistance. Under the assumptions used for facility write-off and operating costs, the average price per pound for irradiation of a product would approach $0.30.

The proposed project, which had the full and active support of top-level management of AEC, Commerce, and Army, generated an avalanche of inquiries and interest on behalf of private companies. As a result, a task force consisting of one representative from each of these agencies was formed, with the mission of meeting individually with companies or groups which expressed serious interest in the project. While business expected that guidance could be provided where requested, a secondary objective was to determine how realistic or attractive the government's offer of assistance was.

Between November 1965 and the following May, after meeting with more than 90 companies, the task force formulated its report[4] and submitted it to their agency heads for approval and implementation. One of the major recommendations was that the DOD procurements (now up to 300 thousand lb per year) be increased substantially and at least doubled during the first 2 years of operations. This would close the gap between the million pounds per year capacity and the guaranteed procurement level and at the same time reduce the cost per pound of product to the DOD. While excess capacity could be used for commercialization efforts or for other product irradiations, few companies were able to foresee sufficient business to fill such a plant and necessarily would attempt to write off the bulk of operating and depreciation costs on only the DOD procurements.

Sufficient industry interest was evident to continue the project, and the AEC undertook preparation of a formal request for proposals (RFP) to solicit firm commitments for participation. The four primary objectives of the pilot-plant project would be:

1. To introduce and test shelf-stable foods in rations for the armed forces in quantities larger than are possible with existing ionizing-radiation facilities.

2. To develop processing methods and solve potential problems associated with scaling up from laboratory to commercial production.

3. To obtain processing costs and project the economics of the process to conditions of full-scale commercial production of radiosterilized foods.

4. To investigate, test, and develop a civilian commercial market for these foods.

The DOD procurement level remained at 300 thousand lb per year, in spite of AEC and Commerce efforts to convince DOD that this figure should be raised. The AEC's earlier offer of $180 thousand for source procurement was raised to $240 thousand as a more realistic price if a machine were selected for the source. It would also be sufficient for the purchase of ^{60}Co from a private supplier if that were the selected source. The RFP[4] was issued on Dec. 19, 1966, to over 130 companies.

Responses were due back to AEC on Apr. 17, 1967. Other companies not on the initial mailing list also requested copies of the RFP, bringing the total number of interested parties to slightly over 200. Figure 1 shows the geographical distribution of interest in the pilot-plant meat irradiator project.

By April 17, ten companies, or groups of companies, as listed in Table 1, had submitted their proposals, and their evaluation by an AEC–Army–Commerce Proposal Evaluation Panel was begun. Evaluation criterions were based primarily on (1) qualifications and experience of the organization and personnel proposed for undertaking the project, (2) the design and capacity of the facility (a conceptual design was required with sufficient information to be presented to allow an independent evaluation of capital costs, processing costs, and general adequacy of the plant for the intended purpose), (3) the plan for introduction of radiation-processed meats into the commercial market, and (4) the amount of government support requested, including the price per pound for DOD procurements.

On June 13, 1967, the Commission approved the selection of the proposal from Irradiated Foods, Inc. (IRRADCO), a new corporation owned by Allen Products Co., Inc., a division of Liggett & Myers Tobacco Co.; Isotopes, Inc., a Teledyne Company; Martin Marietta Corp.; and Uniroyal, Inc. A contract was negotiated and signed on July 17, 1967, and the project was formally under way. Needless to say, the information contained in all 10 proposals to the AEC is held as proprietary or business confidential, including many features of the winning proposal. However, with the permission of IRRADCO, certain information has been released and can be recounted.

From the government's standpoint, there were several especially attractive features of the IRRADCO proposal. First, the facility proposed would have an initial capacity of 3 million lb of radiation-processed product per year. Commitments for irradiated products well over the 300 thousand lb to be purchased by the Defense Supply Agency (DSA), coupled with fairly standard capital equipment write-off procedure, enabled IRRADCO to quote radiation costs per pound which were very reasonable. Although these costs varied with various packaging sizes and containers,

Fig. 1 The distribution of requests for proposals (RFP's) on the pilot-plant meat irradiator.

Table 1 PROPOSALS SUBMITTED FOR PILOT-PLANT MEAT-IRRADIATOR PROJECT

Proposer	In major association with	Location of proposed facility
AEL Food Automation Division, Inc. Stamford, Conn. (Mr. Robert E. Nickerson)	AEL Development & Research, Inc. Radiation Facilities, Inc. Applied Radiation Corp. Air Products & Chemicals Inc. Radiant Energy Processing Corp. Radiation Consultants, Inc.	Camden, N. J. Philadelphia, Pa.
Applied Radiation Corp. Walnut Creek, Calif. (Thomas P. McReynolds) (R. G. Schonberg, Manager)	Holmes & Narver, Inc. Atomic Energy of Canada Limited Bridgeport Foods Corporation King Meat Company San Jose Meat Company Safeway Stores	San Jose, Calif.
Farmbest, Inc. Dennison, Iowa (Frank Crabb, General Manager)	General Electric	Dennison, Iowa
High Energy Processing Corporation New York, N. Y. (John Flynn, President)	Hormel Thermo-Bios Process Plants	Bedford, Mass.
Houston Research Institute, Inc. Houston, Tex. (George A. Peck, Executive Vice President)	Henry House Packing Company Food Industries Research & Engineering Company	Hanford, Wash.
Irradiated Foods, Inc. (IRRADCO) Allentown, Pa. (Carl B. Wootten, Vice President)	Isotopes, Inc. Allen Products Company, Inc. Martin Marietta Corp. Uniroyal Thompson Farms	Allentown, Pa.
Iso Nuclear Corporation New York, N. Y. (William Loeb, President)	John Morrell & Co.	Buffalo, N. Y.
Nuclear Materials and Equipment Corp. Apollo, Pa. (Oscar Gray, Vice President)	Food Industries Radiation Council	Carroll, Iowa
Rad-Mat, Inc. Gaithersburg, Md. (J. Henry Hoskinson, Vice President)	Esskay University of Maryland Food Technology Corporation Hazleton Laboratories	Gaithersburg, Md.
General Radiation Corporation Phoenix, Ariz. (John D. Proynoff, President)	None	Phoenix, Ariz.

they were generally close to earlier AEC estimates—in the neighborhood of $0.30 per pound. When alternatives to facility write-offs are considered, with a minimum of other products (food and nonfood) being processed over the 3-year DSA procurement span, the price per pound can very quickly jump to about $1.50. The added total cost to DSA for the total 900 thousand lb procurement would then jump by a million dollars—a very significant increase.

IRRADCO also chose to bear the full costs of engineering design. The sole monetary support requested of AEC was $185 thousand to fund the commercial purchase of about 400 kilocuries of ^{60}Co. As reported in the Nov. 7, 1967, issue of *Nucleonics Week*,[5] Neutron Products, Inc., will be the ^{60}Co supplier.

Four separate but related contract actions are associated with IRRADCO in the pilot-plant meat irradiator project:

1. IRRADCO–AEC: A contract depicting the obligations of each party relative to design, construction, and operation of the facility, to include test marketing aspects of irradiated foods.

2. IRRADCO–DSA: A contract committing the DSA to procure 300 thousand lb of product for each of the first 3 years of operation at prices agreed to by the two parties.

3. IRRADCO–U. S. Army Natick Laboratories: A no-cost agreement wherein Natick will provide assistance to IRRADCO in special areas of interest related to meat irradiation.

4. IRRADCO–Brookhaven National Laboratory: A no-cost agreement wherein BNL will provide a reasonable amount of technical assistance in the nuclear and engineering aspects of facility design.

As of December 1967, design of the facility by Isotopes, Inc., has proceeded well and on schedule, with a projected design completion in March 1968. Actual construction will begin either in April or after Food and Drug Administration (FDA) approval of radiation-sterilized ham. Construction time is estimated at 12 months.

General Facility Description

The facility is being designed to receive, store, and irradiate a wide range of prepackaged products, including all of the DOD procurement meats, representative meats for the civilian market, and a line of proposed pet foods, at room temperature and at refrigerated temperatures as low as −80° C. The plant will be located in Allentown, Pa., on property owned by Allen Products Company a short distance away from ALPO's present pet food production facilities.

The plant is housed in a building of approximately 6500 sq ft total area and consists of an irradiation facility, including an irradiation chamber, biological shield, source storage pool, source rack and hoist system, product handling system, and refrigeration and ventilation system; a cold room; a blast freezer; an operation control room and quality control room; a treated products storage area; an equipment room; a meat inspector's office; and an incubation cabinet. The plant is designed to permit easy expansion from pilot scale to a full commercial scale.

Construction of the building is concrete block for exterior and interior walls except for the thick concrete biological shield enclosing the irradiation facility, which is of poured concrete. Exterior concrete block walls are faced with brick, while exterior poured concrete walls are vertically fluted to lend an attractive appearance, as indicated in the architect's rendering (Fig. 2).

Canned or packaged meat and pet food products at chilled or frozen storage temperatures are unloaded from trucks at the loading dock at the rear of the building. There is a ramp so that truck unloading and loading are done at floor level of the plant. The products, on pallets or in boxes, are brought through the entrance vestibule into the cold room for temporary storage and, where appropriate, for cooling to desired irradiation temperatures. Individual cans or cartons of product are subsequently loaded into irradiation containers and placed on a conveyor for transport from the cold room through an entrance shielding maze into the shielded and insulated irradiation chamber. Those products requiring irradiation at −80° C (−112° F) are passed from the cold room through the blast freezer from which they are conveyed to the irradiation chamber. The entire irradiation chamber is maintained at the temperature required by the product during irradiation. In order to conserve refrigeration and insulation costs not required in the pilot plant, approximately half of the irradiation chamber is sealed off by a temporary insulating wall, to be removed in the future when plant capacity is to be expanded to commercial production levels.

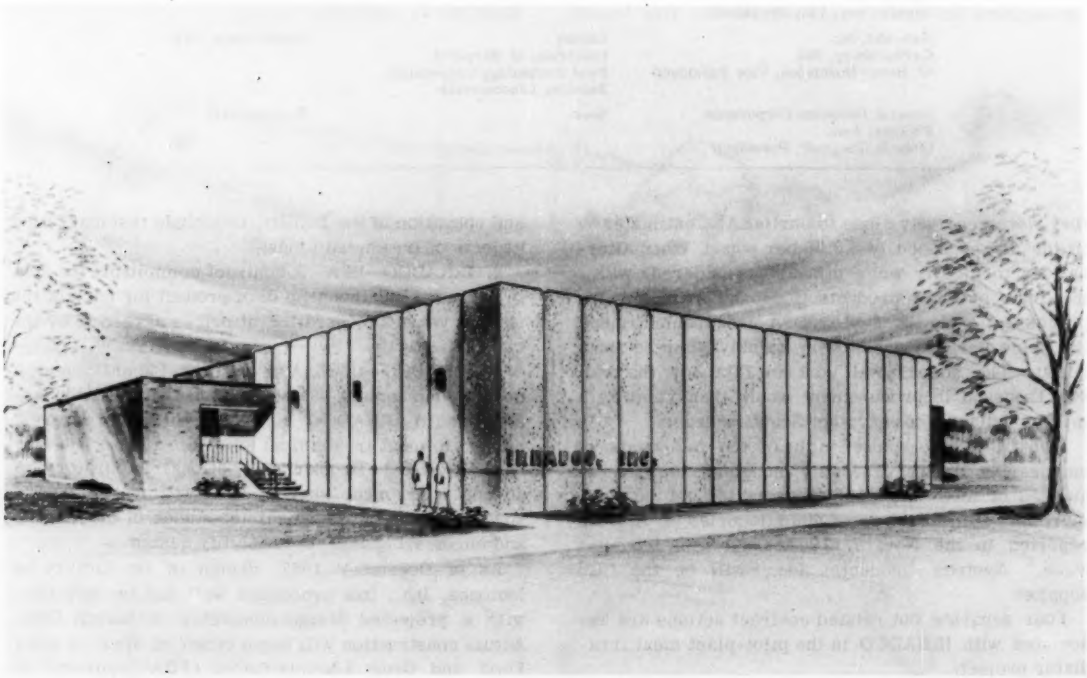

Fig. 2 Architect's rendering of the pilot-plant meat irradiator.

In the chamber the product boxes are automatically transported by the conveying system past the ^{60}Co radiation source, in a configuration that allows 60 boxes in the chamber at any one time. The irradiation chamber width, height, and length are sufficient to accommodate a larger array as part of the designed-in provisions for future expansion of capacity. The source, initially containing 400 thousand curies, is in a vertical planar configuration contained in a rectangular source rack, which is raised to the irradiation position by the source hoist system. Figure 3 shows an isometric drawing of the irradiation chamber.

When not in use, the source is lowered into an insulated storage pool that provides shielding over the source and permits access to the irradiation chamber when the source is stored. The pool also permits simple on-site source loading and rearrangement. The total length of the pool is adequate to permit future installation of a longer source rack containing up to 5 million curies.

At the completion of the irradiation cycle, product boxes are discharged by an output conveyor system to the treated products storage area, where the product is allowed to warm up to room temperature and is then loaded into shipping cartons. A second door adjacent to this area is used for loading completed products on trucks for shipment from the plant.

Control of the entire irradiation and refrigeration facilities plant is maintained from a console in the operation control room, and dosimetry and other quality control procedures are centered in an adjacent quality control room.

An equipment room at the side of the building houses the refrigeration equipment which cools the cold room and the irradiation chamber, the building comfort heating and ventilation equipment, and the water circulating and purification equipment for the source pool.

With the initial source loading of 400 kilocuries, approximately 3 million lb of an average product can be produced per year at an average dose of 4.5 Mrads. This loading is sufficient to last for 3 years before replenishment is needed. At the end of the 3-year period, the throughput is approximately 2 million lb per year.

In commercial configuration, typical product throughput will be 30 million lb per year with a high source utilization efficiency. The source required under these conditions will be about 2.8 Mc of ^{60}Co. This source strength can be maintained by annual replenishment. With a maximum possible fresh source loading of 5 Mc, the eventual throughput could be over 50 million lb per year.

Commercialization

A comprehensive public acceptance and test marketing program will be undertaken by IRRADCO through Thompson Farms Company, a leading Chicago meat packer, to introduce radiation-sterilized ham into normal consumer and institutional channels. It is worthy of note that Mr. John Thompson, President of

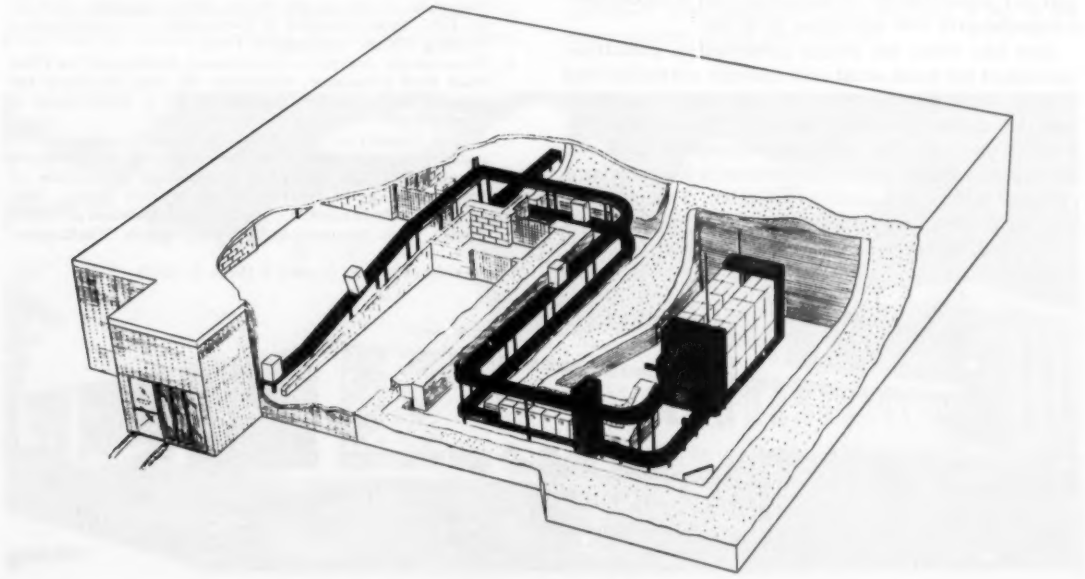

Fig. 3 Schematic of irradiation processing area in the pilot-plant meat irradiator.

Thompson Farms, was named as "Meat Packer of the Year (1967)" by the National Independent Meat Packers Association.

For this commercialization program, canned hams will be prepared in the same manner as those produced for the DOD, except that these commercial hams will be a brand-name product of Thompson Farms. The test marketing and acceptance program will employ the usual techniques used to introduce other more conventional Thompson Farms products, with the addition of a comprehensive distributor and consumer education program to emphasize the techniques and benefits of the radiation-sterilization method of processing. Meetings, seminars, trade fairs, food conventions, and brokers' conventions will be exploited to introduce samples of the new product and tell the irradiated-ham story. Newspaper advertising, prime-time TV commercials, and in-store advertising campaigns will be conducted in selected test market cities as the irradiated ham is produced and made available to supermarket chains and institutional kitchens. If at any point in the testing program the irradiated canned hams prove to be an immediate success, the program would be greatly accelerated and the distribution pattern increased accordingly.

In addition to the Thompson Farms irradiated canned ham product, IRRADCO, with the assistance of Allen Products Company, will develop and introduce a new line of radiation-sterilized pet foods in easy-open containers. This new product will supplement ALPO's all-meat pet food line and will be the only product of its kind on the market. The irradiated pet foods will be introduced by a limited, initial commercial acceptability investigation and a subsequent comprehensive test marketing program.

Just like foods for human consumption, radiation-processed pet foods must also undergo evaluation and testing when food additives are involved, and their sale is subject to FDA approval. The fact that the food is intended for animal consumption does not necessarily lessen FDA's requirements for assurance of their safety and nutritional value. The pet food test marketing program will therefore be preceded by studies necessary to support a petition for FDA clearance.

When cleared the new pet food product will be marketed in selected metropolitan areas on the same basis used to test other ALPO products. This normally includes free sample cases, strategic newspaper advertising, local spot television commercials, and other advertising techniques.

In addition to the radiation sterilization of meat and pet foods, at doses in the ranges 4.5 to 5.6 Mrads, and 3.5 to 5.6 Mrads, the irradiator, because of its versatile design and flexibility of conveyor (without modification), can be used to process a wide range of other products requiring doses in the pasteurization range.

Judging from the number of continuing inquiries of interest in this overall project, one would expect that its success or failure will, in large part, dictate the probable near future of food irradiation. It was, in fact, undertaken with these thoughts in mind. Many possible pitfalls have been and are being flagged and worked around; hopefully, the parties involved will find the solutions to make the project an unqualified success. (FEM)

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Section

III

Isotopes and Radiation Technology

Process Radiation Development

Oregon State University Radiation Center

The Radiation Center of Oregon State University, Corvallis, is an institutional facility designed to accommodate instruction and research programs in nuclear science and nuclear engineering originating anywhere in the University as well as to provide limited off-campus services. Construction of the Radiation Center consisted of two phases. The first phase, construction of offices and laboratories, was completed in June 1964. The second phase, construction of a research reactor, was completed in March 1967.

Soon after the beginning of the nuclear era in 1945, the faculty at Oregon State University began developing peaceful uses for nuclear energy in various fields. Radioisotopes were used as tools in a number of research endeavors.

In the succeeding decade, instruction and research programs in nuclear science and engineering were implemented in the various schools at a rapid pace. Major developments included the expansion of course offerings in several departments, construction of a 37-in. cyclotron by the members of the Department of Physics, and installation of an AGN-201 training reactor. By 1960, ~10 thousand sq ft of laboratory space in 11 departments were being used for research related to radioisotopes and nuclear energy. Presently, Oregon State University offers B.S., M.S., and Ph.D. degrees in nuclear engineering; M.S. and Ph.D. degrees in nuclear physics, radiation chemistry, radiochemistry, radiation biology, radiological physics; and M.S. degree in radiological health.

In order to accommodate research and graduate instruction programs in the broad areas of nuclear science and engineering, long-range plans were made in 1961 for program development and improvement of facilities. The Radiation Center building is one of the major facets of this plan (Fig. 1).

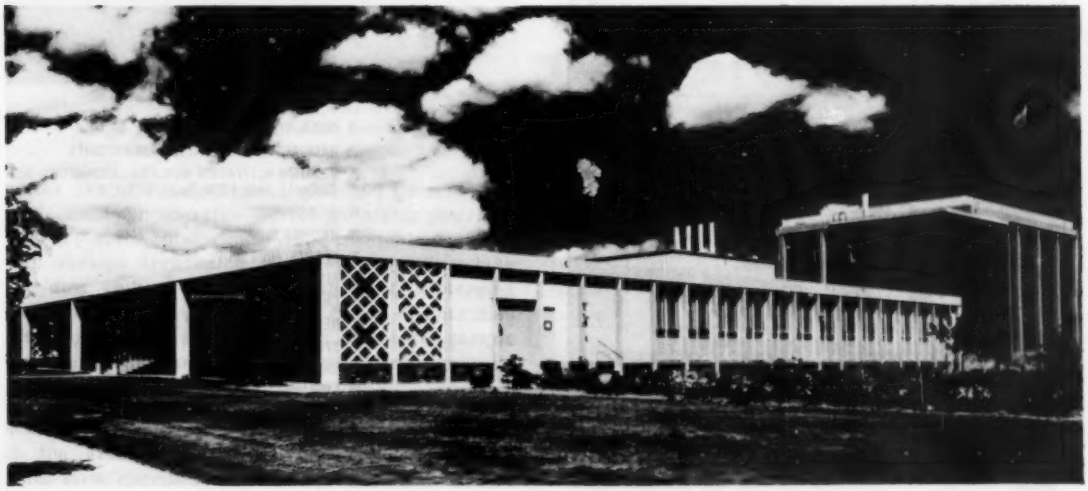


Fig. 1 Oregon State University Radiation Center.

Functions

The Radiation Center and associated facilities were established to provide internal and off-campus instruction, and research and development programs involving the use of radioisotopes, ionizing radiation, fast neutrons, and thermal neutrons. The Center provides such services as:

Training programs in nuclear engineering and nuclear science. A large number of graduate students in engineering and science receive training in radioisotope methodology, nuclear engineering, neutron activation analysis, radiochemistry, radiation biology, and similar areas at the Center.

Consultation in the application of radioisotopes and radiation in research.

Safety analysis of radioisotopes and radiation operations.

Measurement of various types of ionizing radiation.

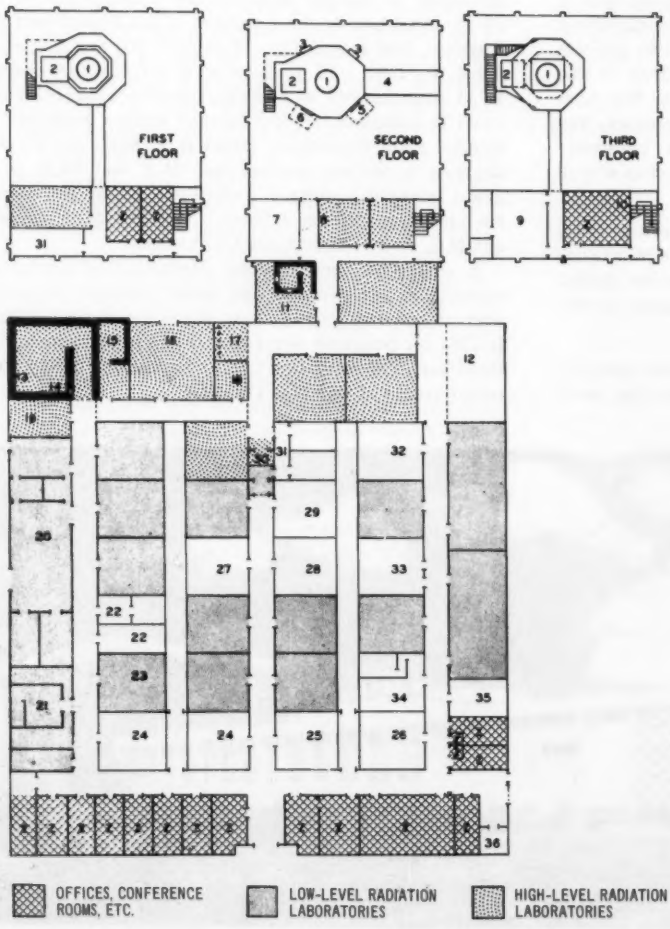
Irradiation experiments involving X rays, gamma rays, or neutrons.

Exploratory programs on the novel uses of radioisotopes and radiation.

Facilities

The Radiation Center occupies ~42 thousand sq ft of floor space (Fig. 2), including ~10 thousand sq ft for the nuclear reactor facility. The total cost, including instruments, was more than $2 million; funding was provided by the state of Oregon, the National Science Foundation, the National Institutes of Health, and the Atomic Energy Commission.

Housed in the Center are various types of laboratories to handle programs involving the use of radioisotopes and ionizing radiation. These include a hot



LEGEND

1. OREGON STATE TRIGA REACTOR (OSTR)
2. BULK SHIELDING TANK
3. BEAM PORTS
4. THERMAL COLUMN FACILITY
5. NEUTRON RADIOGRAPHY FACILITY
6. NEUTRON-DIFFRACTION FACILITY
7. MECHANICAL ROOM
8. PNEUMATIC SAMPLE TRANSFER SYSTEM TERMINAL
9. OSTR CONSOLE
10. SUBCONSOLE OF CDC-3300 COMPUTER
11. HOT-CELL FACILITY
12. OREGON STATE AGN REACTOR (OSAR)
13. SUBCRITICAL ASSEMBLY
14. 250-kvp X-RAY GENERATOR
15. 300-kvp MAXITRON X-RAY GENERATOR
16. RADIOACTIVE-WASTE-DISPOSAL FACILITY
17. RADIOISOTOPE STORAGE FACILITY
18. RADIOACTIVE-WASTE COLD STORAGE
19. 3300-CURIE ^{60}Co SOURCE
20. LARGE ANIMAL LABORATORIES
21. SMALL ANIMAL LABORATORIES
22. COLD LABORATORIES
23. AQUARIA
24. INSTRUMENT ROOMS
25. RADIOACTIVITY COUNTING LABORATORIES
26. NEUTRON ACTIVATION ANALYSIS LABORATORY–4096 CHANNEL ANALYZER, Ge(Li) DETECTOR
27. SHOP STORAGE
28. MACHINE SHOP
29. ELECTRONICS SHOP
30. AIR LOCK
31. CHANGE AREA
32. NEUTRON RADIOGRAPHY LABORATORY
33. STOCK ROOM
34. DARKROOM FACILITY
35. LIBRARY
36. SOLVENT STORAGE ROOM

Fig. 2 Floor plan of Radiation Center.

cell, high-level radiochemical laboratories, and other laboratories such as an animal laboratory and a plant laboratory.

Major facilities include:

The Oregon State AGN-201 Training Reactor (OSAR). This reactor is licensed for 0.1-watt steady-state operation.

The Oregon State TRIGA Research Reactor (OSTR) (Fig. 3). Built by Gulf General Atomic, this facility

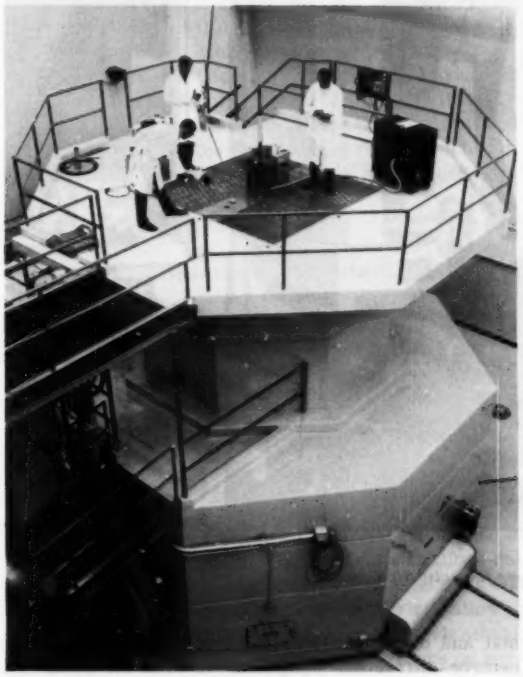


Fig. 3 Oregon State TRIGA Reactor.

makes use of stainless-steel-clad fuel elements and is licensed for operation at 250 kw steady power or 1200 Mw in the pulsing mode. The reactor is equipped with various irradiation facilities including a bulk shielding tank, a tangential beam port, a piercing beam port, two radial beam ports, a 40-specimen rotating sample rack (Fig. 4), a pneumatic sample transfer system, and a graphite thermal column.

A 3300-Curie ^{60}Co Source (Fig. 5). This gamma source is used for numerous irradiation experiments in the areas of radiation microbiology, genetics, solid-state chemistry, and food preservation. Radiation chemistry is one of the major research programs at the Center. Studies in this area include radiolysis

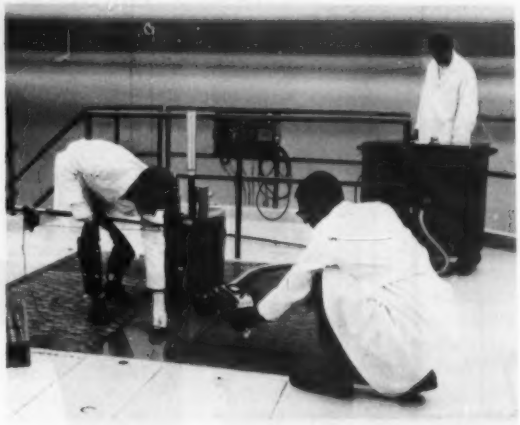


Fig. 4 Port to rotating rack adjacent to OSTR core.

of aqueous solutions of inorganic compounds and interaction of radiation with DNA and related compounds. The uniquely designed irradiator is equipped with a 5-in. irradiation chamber with provisions for environmental control.

X-Ray Generators. Five X-ray generators, including a 300-kvp Maxitron, are used for radiation biology and applied programs.

A Neutron Source. A 5-curie Pu–Be neutron source is used in the nuclear engineering program.

Specialized laboratories include:

Neutron Activation Analysis Laboratory. This laboratory is equipped with a 4096-channel analyzer, a 400-channel analyzer, and associated detectors, in-

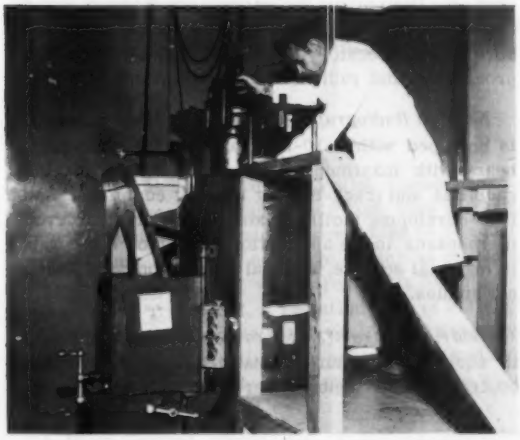


Fig. 5 A 3300-curie ^{60}Co irradiator.

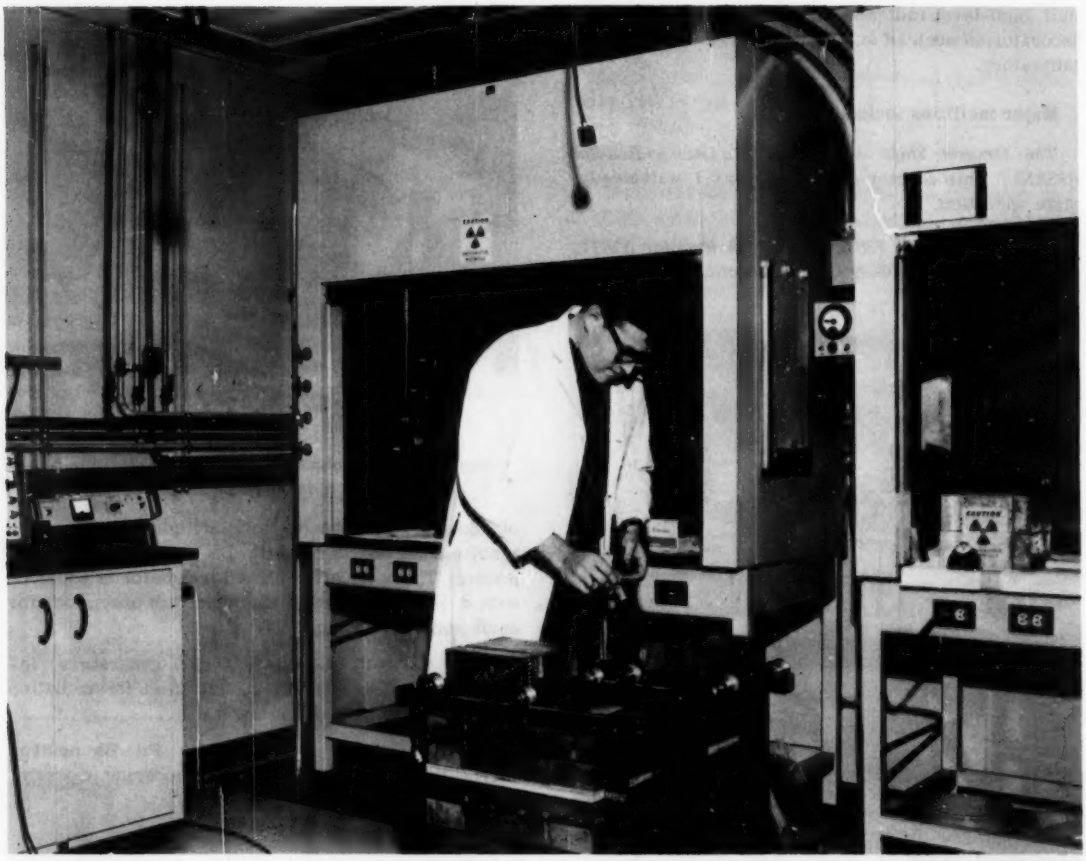


Fig. 6 Radiochemical laboratory for activation analysis.

cluding a lithium-drifted germanium detector. Irradiated samples can be transferred from the reactor core to the laboratory in a matter of a few seconds for processing and radioactivity measurements (Fig. 6).

Neutron Radiography Laboratory. This laboratory is equipped with a 10-in.-diameter thermal-neutron beam with maximum angular divergence of ±0.6°, gadolinia and track-etching imaging equipment, and a film-developing facility. Extensive efforts are devoted to research in the application of neutron radiography in material science, medical applications, and biological studies.

Neutron-Diffraction Laboratory. This laboratory is equipped with an automatic and manual remote-control crystal table, a four-angle full-circle goniostat and diffractometer, and associated devices. The neutron-diffraction equipment is used for research in molecular structures, metallurgy, and material science.

Other laboratories, such as those used for training, are equipped with portable laboratory benches. Utilities are housed along the wall, thereby permitting maximum flexibility in the use of laboratory space. The high-level radiochemical laboratories are exhausted through absolute filters, and the building uses a one-pass ventilation system throughout.

These complete modern facilities are certainly a credit to the Oregon State Board of Higher Education, to the OSU Administration, and particularly to the Coordination Board and Executive Advisory Committee of the Radiation Center. (PSB)

Radiosterilization of Medical Products*

Abstract: The proceedings of the 1967 IAEA-sponsored Budapest symposium on the use of radiation to sterilize pharmaceuticals, biological tissues, instruments, and prosthetic devices and to prepare vaccines are reviewed here. Radiation sensitivity of and testing for microorganisms, economics of radiation sterilization, and final recommendations for an international code of practice are also covered.

The use of ionizing radiation for sterilizing medical supplies, e.g., plastic hypodermic syringes, is a well-established industrial process.[1–4] The literature (177 references) on radiation sterilization of medical supplies, prosthetic devices, and drugs and on production of vaccines was reviewed in a 1966 IAEA publication,[5] and drafts of a code of practice were circulated earlier.[6,7] In 1967 the IAEA sponsored a symposium on sterilization of medical products, the proceedings of which are reviewed here.

General Principles of Radiosterilization

The conference was introduced with a review (105 references), by S. A. Goldblith from the Massachusetts Institute of Technology, of basic radiation sterilization information. Published results indicate that, in general, the relative radiation sensitivities of bacterial species are not related to their sensitivities to chemicals or heat. The initial level of bacterial contamination, the gas-phase composition, the temperature, and the degree of hydration affect the percentage of the organisms killed by a given dose of radiation. Certain chemicals and heat conditions enhance the effect of ionizing radiation of bacteria and their spores. The mode of action of the radiation on the organisms is still very incompletely understood, as is the effect of postirradiation conditions on survival of subsequently introduced organisms. Although radiation-resistant mutants may theoretically develop when a strain is irradiated for successive generations, Goldblith thinks that no significant mutation will result from commercial processing, where products are irradiated only once.

Pharmaceuticals and Bioproducts

In Hungary some drugs not hitherto discussed in the literature have been sterilized by the generally accepted 2.5-Mrad sterilizing dose. Irradiation of estradiol benzoate and stilbestrol dipropionate gave satisfactory products. More study is needed on deoxycorticosterone acetate, digoxine, procaine hydrochloride, and progesterone, which showed no measurable decomposition but did change color. Hydrocortisone was measurably decomposed; however, heavily infected hydrocortisone eye ointment, although not sterilized by 5.0 Mrads, showed little decomposition, and radiation-sterilization conditions can probably be worked out. Certain sealed aqueous solutions that cannot be heat sterilized—0.1% atropine, 1.0% morphine, and 2% lidocaine—showed decomposition with 2.5-Mrad doses, but sulfite offered some protection to the atropine. Preliminary studies on thyroid extract indicate that it might be suitable for radiation sterilization. Human immunoglobulin G was altered by 1.5 or 2.5 Mrads irradiation.

Various medicines, solutions, and instruments used in ophthalmology are sterilized in England. These products include a polystyrene syringe filled with physiological saline, certain eyedrops, and unidose containers of drugs.

Basic studies on the effects of ^{60}Co irradiation on vitamin B_6 and folic acid, on the tetracyclines, and on various fractions of human blood-plasma proteins were reported by IAEA staff members. A paper from Mexico presented preliminary results which indicate that radiation sterilization may be a satisfactory method of sterilizing human plasma containing the hepatitis virus.

The results of French tests on antitetanus serum and on polyvalent gamma globulin in glass vials indicated that the maximum radiation dose that can be used on these products was 1.5 Mrads. When exposed to 3.3-Mrad sterilizing doses, multipuncture polymethacrylate rings were discolored, and self-injecting polyethylene ampule–syringes with neoprene fittings gave off a goaty odor.

Biological Tissues

All material stored in the Polish tissue bank is sterilized by gamma irradiation (^{60}Co). This material includes human bone, which is preserved by lyophilization; human and calf cartilage, which is stored in serum; and cow fasciae, which are fixed in 70% ethanol before being irradiated. A radiation dose of 3.3 ± 0.5 Mrads is used. Experimental studies on rat liver have showed that, of all sterilization-preservation methods used, gamma irradiation decreases the protein solubility the most—about 65%.

A West German comparison of gamma- and electron-irradiated catgut indicated that gamma irradia-

*Proceedings of a Symposium, Budapest, June 1967, IAEA, Vienna (STI/PUB/157), announced in *Isotopes and Radiation Technology*, 5(1): 84 (Fall 1967).

tion gives a better product. For example, with a 2.5-Mrad dose, the gamma-irradiated product showed 8% reduction in tensile strength, while the electron-irradiated one showed 15%. The temperature at which shrinkage occurred was 3 to 6°C lower and degradation was more rapid in the electron-irradiated product. The Hungarians also think gamma sterilization of catgut is superior to other methods and consider that 3.5 Mrads can be relied on as a sterilizing dose. Tests in the United States on ^{60}Co-irradiation sterilized sutures indicated that 2.5 Mrads provides a safety factor of 10^4 for *Staphylococcus faecium* and 10^7 for *Bacillus pumilus*.

British work on sterilization of homograft aortic valves indicated that 2.5 to 3.0 Mrads is an acceptable alternative to other sterilizing methods. A 3-Mrad gamma-irradiated valve can be used instantly, while a freeze-dried one requires 30 min to be reconstituted at the operating table.

Vaccine Production by Ionizing Radiation

The results of basic studies done in the USSR indicate that multiple irradiations increase the radiation resistance of a strain of bacteria. On the more practical level, typhoid and dysentery vaccines were made by irradiating (^{60}Co) bacterial preparations to 1.5 to 2.0 Mrads. These doses are higher than the lethal dose by a factor of about 10. The results of tests on the preparations were encouraging.

The French have determined the doses of alpha (radon), neutron, 210-kv X, boron-fission, ^{60}Co gamma, reactor neutron and gamma, and 150-Mev proton radiation required to completely suppress virulence of a number of pathogens. They conclude that the irradiated organisms have an antigenic power at least equal to that of heat-treated preparations. The comparative radiation sensitivities of various bacteria and viruses were also reported from Montreal.

A review, by T. A. Miller of the University of Glasgow, of the literature (61 references) on irradiated larval vaccines shows that intensive work has been done in this field, particularly in the past 15 years. Two irradiated vaccines used commercially in veterinary practice—*Dictyocaulus viviparus* and *D. filaria*—for several years have proved to be of economic value. An irradiated larval vaccine for hookworm in dogs is expected to be available in a few years.

Medical Devices and Supplies

The use in Denmark of radiation sterilization for medical supplies began in 1959 with the sterilization of an oxygenator for a heart–lung machine in the ^{60}Co experimental facility. These devices cannot be sterilized by either heat or ethylene oxide. Considerable work has been done on determination of doses required for sterilizing, and both this and the accelerator sterilizing unit were described. From England were reported data on gamma sterilization of tygon tubing for a heart–lung machine and of heart valve prostheses, together with results of tests on disposable hypodermic syringes for use in determining doses required for sterilization.

Radiation Sensitivity of Microorganisms and Microbiological Testing

In a paper from the United States, the sterilization of medical devices by radiation was compared with that by ethylene oxide. The conclusion reached is that each method has advantages for some cases, and a number of factors must be considered in selecting which method to use.

The survival of both vegetative and spore forms of bacteria in pharmaceutical powders and factors affecting survival and recovery of spores have been studied in Hungary. Sterility tests on preparations labeled with ^{131}I, for use in diagnosing human diseases, were described.

Technical and Economic Aspects of Radiosterilization

The economic importance of radiation sterilization is shown by a list (Table 1) of 29 facilities—65% of which are for use with medical supplies—which operate with 20 kilocuries or more of ^{60}Co. A Canadian comparison of plant capacities and processing costs in ^{60}Co sterilization plants has been reprinted in *Isotopes and Radiation Technology*.[4] A British paper on the relation of plant design to product cost was also presented at the conference. From the USSR came descriptions of several gamma installations, using both ^{60}Co and ^{137}Cs, and a summary of the present state of development and design of large irradiation plants.

Code of Practice for Radiation Sterilization of Medical Products

A Code of Practice for Radiation Sterilization of Medical Products, which had been extensively discussed at previous meetings, was presented to the conference. In a review of the code, L. O. Kallings, of the Stockholm National Bacteriological Laboratory, stated: "The preparation of such a [code] will constitute a challenge to operators working with other sterilizing procedures." (MG)

Table 1 COMMERCIAL AND SEMICOMMERCIAL PLANTS USING MORE THAN 20,000 CURIES OF ^{60}Co*

Place	Process	Owner	Designed and built	Capacity, curies
Australia				
Dandenong	Sterilization of goat hair and medical supplies	Gamma Sterilization Pty. Ltd.	UKAEA, Westminster Carpets Pty. Ltd.	2,000,000
Canada				
Mont St. Hilaire	Food-irradiation research	Atomic Energy of Canada Limited	Atomic Energy of Canada Limited	600,000
Ottawa	Mobile food-irradiation demonstration	Atomic Energy of Canada Limited	Atomic Energy of Canada Limited	42,000
Peterborough	Sterilization of medical products	Ethicon Sutures Ltd.	Atomic Energy of Canada Limited	100,000
France				
Lyons (Dagreux)	Industrial irradiation service	C.L.A.A.		1,000,000
Germany				
Hamburg	Sterilization of medical products	Ethicon GmbH.	H. S. Marsh Ltd.	750,000
Melsungen	Sterilization of sutures	Braun Co.	Sulzer Bros.	600,000
India				
Trombay	Food-irradiation research Sterilization of medical products	Indian Dept. of Atomic Energy	Atomic Energy of Canada Limited	100,000
Israel				
Rishon-le-Zion	Food (especially fruit) irradiation	Isotopes and Radiation Enterprises Ltd.	Nuclear Materials and Equipment Corp.	30,000
Italy				
Bologna	Sterilization of disposable syringes	I.C.O. S.p.A.	H. S. Marsh Ltd.	500,000
Netherlands				
Wageningen	Food irradiation	Profbedri if Voed bestraling sel.	H. S. Marsh Ltd.	250,000
New Zealand				
Upper Hutt	Sterilization of medical products	Tasman Vaccine Laboratory Ltd.	Atomic Energy of Canada Limited	600,000
Sweden				
Thoern Island, nr. Gothenburg	Sterilization of medical products	Helinos AB	H. S. Marsh Ltd.	1,000,000
Turkey				
Iskenderun	Grain irradiation	UN Development Program	Nuclear Chemical Plant Ltd.	360,000
United Kingdom				
Wantage	Pilot-scale demonstration plant	UKAEA	Rubery Owen Organisation	500,000
Slough	Sterilization of medical products	Johnson's Ethical Plastics Ltd.	H. S. Marsh Ltd.	500,000
Edinburgh	Sterilization of medical products	Ethicon Inc.	Nuclear Chemical Plant Ltd.	150,000
Reading	Sterilization of medical products	Gillette Industries Ltd.	H. S. Marsh Ltd.	800,000
Sheffield	Sterilization of surgical blades	Swann Morton Ltd.	Vickers-Armstrongs	75,000
Wantage	Sterilization of animal diet etc.	UKAEA	UKAEA	500,000
United States				
Dawsonville, Ga.	Wood–plastic materials and service irradiation	Lockheed-Georgia Co.		250,000
Hawaii, Honolulu	Fruit irradiation	State of Hawaii/USAEC	Nuclear Materials and Equipment Corp.	250,000
Idaho Falls, Idaho	Food irradiation—potatoes	Rogers Bros./Nuclear Materials and Equipment Corp.		30,000
Lynchburg, Va.	Radiation processing of plastic–impregnated wood	American Novawood Corp.	Vitro Engineering Co.	400,000
Midland, Mich.	Manufacture of ethyl bromide	Dow Chemical Co.		30,000
San Angelo, Tex.	Sterilization of medical products	Ethicon Inc.	Atomic Energy of Canada Limited	750,000
				1,500,000
Somerville, N. J.	Sterilization of medical products	Ethicon Inc.	Atomic Energy of Canada Limited	750,000
				1,500,000

*Presented by S. Jefferson of UKAEA, England, and C. G. Crawford of Radona Irradiations AB, Sweden.

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Section

IV

Isotopes and Radiation Technology

Isotopic Heat and Power Development

Radioisotopic Power Sources for Human Implantation*

By W. H. Pennington,† D. W. Cole,‡ and W. E. Mott§

Abstract: The U. S. Atomic Energy Commission, in cooperation with the National Heart Institute of the National Institutes of Health, is investigating the feasibility of developing a radioisotope-powered thermodynamic blood pump for an implantable circulatory support system. Conceptual design requirements as well as bioengineering problems and the candidate radioisotopes are discussed.

For over 10 years the U. S. Atomic Energy Commission has sponsored programs for direct conversion of the heat from the decay of radioisotopes to electricity. One of the first programs, Systems for Nuclear Auxiliary Power (SNAP), resulted in a ^{210}Po-powered 2-watt device that was demonstrated at the International Trade Fair in Tokyo in 1959. Later, ^{238}Pu-powered models of this unit were used for supplying power to U. S.-launched satellites, and one of these units has successfully completed more than 5 years of operation.

The successful development of SNAP devices has demonstrated the feasibility of using radioisotopic-energy sources for applications requiring long-term, unattended operation. This has led to considerations of such sources for implantation in the human body to power various assist devices and artificial organs. Two programs are currently under way in cooperation with the National Heart Institute of the National Institutes of Health. The implantable radioisotope-powered cardiac pacemaker program is briefly discussed. The four conceptual design studies, currently in progress and scheduled for completion by Dec. 29, 1967, to investigate an implantable radioisotope-powered thermodynamic circulatory support system are discussed in detail. Bioengineering problems associated with long-term implantation of radioisotope sources and candidate radioisotopes are also discussed.

Implantable Radioisotope-Powered Cardiac Stimulator or Pacemaker

There is a high degree of automatism about the beating of the heart. And one important stimulus is the inherent rhythmic contraction characteristic of cardiac tissue. The wave of contraction that spreads over the heart originates in a small area of specialized tissue, the pacemaker, in the wall of the upper right quadrant. A relatively common cardiac disease, heart block, involves blocking of impulse conduction to the lower quadrants, the ventricles, i.e., there is interruption of the normal stimulus to the heart.

Approximately 10 thousand persons with heart block have been helped by the implantation of battery-powered pacemakers, which stimulate the heart by providing electrical shocks at a nominal rate of about 70 per minute through leads to the left ventricle of the heart. These battery-powered devices require replacement approximately every 2 years. With the objective of reducing the frequency of implantation surgery, Nuclear Materials and Equipment Corporation (NUMEC), Apollo, Pa., is carrying out research under the sponsorship of the AEC, on a radioisotope-powered pacemaker with a minimum life of 10 years.

The approximately 97-g pacemaker will be powered by a small (~0.2 g) ^{238}Pu source, which will supply 160 μw of electrical power by a thermoelectric conversion system.

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Implantable Radioisotope-Powered Circulatory Support Systems

Cause of death—heart disease is the obituary for more than one-half million Americans each year. Of the total of more than 10 million Americans who currently have some form of heart disease, many could be helped by a circulatory support system, i.e., an assist or total-replacement blood pump. In recent years, externally powered blood pumps to assist the left ventricle have been used successfully during heart surgery and the recovery period. However, as surgical techniques develop and improve, there will be a need for completely implantable circulatory support systems for long-term use.

The U. S. Atomic Energy Commission (AEC) and the National Heart Institute (NHI) of the National Institutes of Health recently initiated a cooperative program to investigate the feasibility of developing an implantable radioisotope-powered blood pump, i.e., a system in which the radioisotopic decay energy is converted to heat energy and then to mechanical energy to pump the blood. The kinetic energy of the electromagnetic decay or charged-particle products of radioisotope decay may be transformed into mechanical energy either directly (dynamic conversion, i.e., transformation from heat energy using moving parts), or indirectly through a preliminary conversion to electricity (thermoelectric or thermionic conversion). Thermodynamic converters were selected for the AEC–NHI studies because they offer higher overall conversion efficiencies than thermoelectric or thermionic converters, namely, 20% as compared to 3 to 5% and 11 to 13%, respectively. Higher conversion efficiencies reduce the amount of radioisotope required and hence the weight of the device and the amount of waste heat to be dissipated.

The functional goals of circulatory support devices, whether they be heart assist devices or total heart replacements, include:

1. Return of blood circulation to such a level that useful activity by a patient may be resumed
2. Sufficient sensitivity to changing activity and emotional levels that a patient is not handicapped in a normal social environment
3. A level of reliability such that both patient and associates can accept the fact of implantation without apprehension
4. Availability at a price that would allow those who could benefit from such a device to acquire one
5. Biological compatibility with body tissues and fluids for an indefinite period of time
6. Implantability with surgical risks no greater than routine current cardiac surgery
7. Capability of widespread use without presenting a risk or nuisance to the general public as rehabilitated patients move about freely

As presently conceived, the components of a circulatory support system would include (1) an energy supply located in the abdominal cavity, (2) a blood pump located in the region of the natural biologic heart, (3) some form of power transmission between the energy supply and the blood pump, and (4) a control system to regulate the blood pumping power; the energy supply is to provide a variable power output between 1 and 7 watts of mechanical energy (Fig. 1).

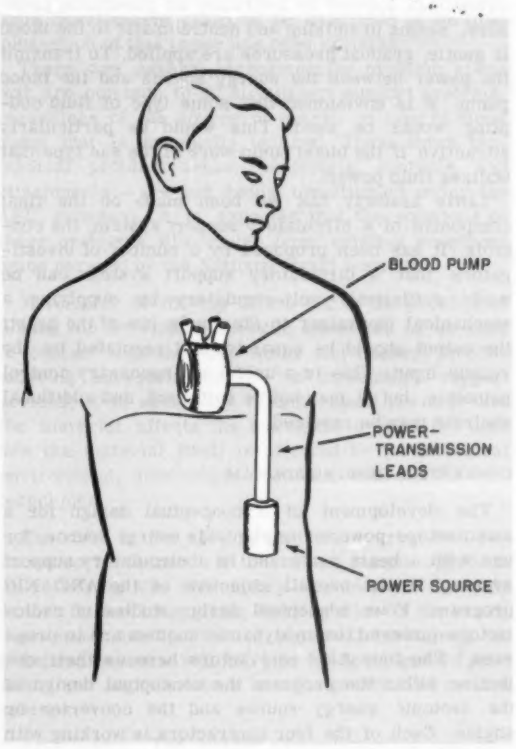

Fig. 1 Components of circulatory support system excluding the control system to regulate power output, which may be part of the energy supply or power-source component.

The energy supply consists of a radioisotopic energy source, a thermodynamic converter, and a heat sink. The radioisotope source must be suitably encapsulated to provide for containment of the material under any foreseeable adverse conditions such as external impact against a solid object or slow chemical reaction between the isotope and the container material. The thermodynamic converter will convert the thermal energy from the heat source into mechanical energy to drive the blood pump. The amount of heat generated by the power supply to be rejected to the heat sink is comparable to that developed by other organs such as the liver, brain, or

heart. The heat generated by these organs is normally removed by the blood and eventually dissipated from the body at the optimum rate to maintain and control body temperature. The blood also appears to be the optimum heat-sink transfer medium for an implantable energy supply.[1]

The consensus of investigators working on blood pumps is that the pump output should be similar to that of the natural heart.[2] It is felt that the collapsible bag or sac-type blood pump, with the repeated squeezings applied by hydraulic or pneumatic pressure, seems promising and nontraumatic to the blood if gentle, gradual pressures are applied. To transmit the power between the energy source and the blood pump, it is envisioned that some type of fluid coupling would be used. This would be particularly attractive if the blood pump were of the sac type that utilizes fluid power.

Little headway has yet been made on the final component of a circulatory support system, the controls. It has been proposed by a number of investigators that a circulatory support system can be made sufficiently self-regulatory by supplying a mechanical equivalent to Starling's law of the heart: the output should be equal to, and regulated by, the venous input. This is a useful and necessary control principle, but it may not be sufficient, and additional controls may be required.

CONVERTER-DESIGN PROGRAM

The development of a conceptual design for a radioisotope-powered implantable energy source, for use with a heart pump and in a circulatory support system, is the overall objective of the AEC–NHI program. Four conceptual design studies of radioisotope-powered thermodynamic engines are in progress.[3] The four AEC contractors have as their objective within the program the conceptual design of the isotopic energy source and the converter or engine. Each of the four contractors is working with a different dynamic engine or converter conceptual design. Typical of the conceptual designs being studied is the following description of a small steam engine.

> In a boiler adjacent to a radioisotopic energy source, recycled water is converted to steam, and the steam passes into an expansion chamber where it drives a piston through its power stroke. The return stroke of the piston transfers the exhaust steam to a condenser which acts as a heat sink. The condensate is then pumped back to the boiler, completing the cycle. The piston would probably be directly connected to a hydraulic pump which would in turn power the blood pump through suitable controls.

Of the dynamic heat-engine systems, the Rankine cycle and the Stirling cycle are the two systems under consideration. The Rankine cycle uses a two-phase substance, such as water or mercury, as a working fluid, and the prime mover is a rotating engine. The Stirling cycle uses a gas, such as helium, as the working fluid, and the prime mover is a reciprocating engine.

In the engine or converter development, a three-phase program has been planned. Phase I covers conceptual design studies. Of the four concepts being studied, two are Rankine-cycle steam engines, one using a linear drive and the other a rotary drive, and two are modified Stirling-cycle engines using helium as the working fluid. The four contractors are performing parametric analyses to determine the fundamental relationships between the physical parameters and the engine performance. The contractors are also to identify, and to provide an assessment of, major technical and engineering problems associated with their concept and to estimate time and resources required for complete engine development. Based on these studies, it is envisioned that one or possibly two concepts will be carried into Phase II of the program, which calls for an experimental effort to obtain more advanced information and data on:

1. The relationship between the configuration of components and the associated fluid flow, heat transfer, and thermodynamic processes
2. Materials and components
3. Engine lifetime and reliability
4. The time and resources required for follow-on engine development program

Phase III will be concerned primarily with engine construction and testing. It will involve adjusting of the configuration of the engine and fixing of the components to obtain the required performance and endurance. To accomplish the objectives of this phase of the program, the following tasks are envisioned:

1. Investigation of strength and endurance of components under environmental conditions
2. Operation of components and the complete engine at specified performance points
3. Identification and modification of components that fail because of vibrational and thermal stresses or deficiencies in design, materials, or fabrication techniques
4. Functional engine tests in parallel with individual component tests

Throughout the engine development program there will be a close interface with programs on development of other components of the system so that upon completion of this Phase III effort the entire circulatory support system will be available for clinical evaluation.

BIOENGINEERING PROBLEMS

Endogenous Heat. The amount of excess heat that must be dissipated in the body by a circulatory support system is greatest for a radioisotopic energy source. The combination of a radioisotopic energy source with a thermal storage medium effectively

reduces the quantity of radioisotope fuel required, since with thermal storage it is not necessary to provide the maximum thermal power input for the peak blood pump requirements. Instead, excess thermal energy can be stored during periods of minimum blood pump output as the latent heat of fusion of the thermal storage material and is available during periods when the blood pumping power requirements are above average. Based on analyses performed to date, it appears that the plan of using the body surface area as an external heat exchanger with the blood as a coolant medium to transport the heat from the internal heat exchanger or heat sink of the energy source to the surface of the body is entirely realistic.[4] To get a feeling for the quantity of heat that must be dissipated, assume that it is possible to achieve an overall power conversion efficiency of 15%, i.e., thermal power input to blood pump output. If the blood pumping power requirements vary between 1.5 watts during periods of rest and 4.0 watts during periods of moderately high activity, then the quantity of heat to be dissipated is between 22 and 25 watts.

Since the nature of the body temperature control does not lend itself to analysis, it has been necessary to undertake an experimental program to determine the limits of heat dissipation in the body. One probable limitation associated with heat rejection is the tolerable local temperature applied to the circulating blood. Another possible limitation is the capacity of an animal to adjust physiologically to increased heat loads without harm to critical organs or impairment of normal functions.[4] At the present time the National Heart Institute is sponsoring two efforts to investigate the effects of additional endogenous heat using electrically heated blood heat exchangers. In one program[1] mongrel dogs are being used, and in the other program[4] miniature swine are the animals being subjected to experimentation. Experimental results to date tend to indicate that a blood-cooled heat exchanger is a feasible method of rejecting waste heat from an internal power source and that a thermal load of up to 50 watts may be tolerated by the human body.

The AEC has fabricated one 15-watt and one 25-watt ^{238}Pu-fueled heat source to supplement the data from the experiments on the electrically heated dogs. The use of the radioisotopic heat sources allows more realistic evaluation of the endogenous heat problem, especially as it pertains to a radioisotope-powered circulatory support system. However, the radioisotopic energy source is hot during implantation, which requires some modification of the surgical procedures used on the electrically energized heat exchangers. This means that the animals have to adapt immediately to the full thermal power output, in addition to having to recover from surgery. This is not the case with the electrically heated units, where the thermal load to the blood can be gradually increased after the dog has recovered sufficiently from the implantation.

Radiation. A bioengineering problem that is unique to an implantable radioisotopic energy source is that of the nuclear radiation produced by the isotope. The level of radiation that can be tolerated from an implantable power source is not known with certainty at this time. In an effort to minimize the radiation effects from an implantable source, a radioisotopic fuels development effort to be described in the final subsection of this paper has been initiated.

There are several bioengineering problem areas that are common to all circulatory support systems, regardless of the source of energy or type of blood pump that is eventually utilized. These three biomedical problem areas—materials, controls, and attachments—are not being investigated under the AEC program. It is expected that the solutions to these problems will evolve from existing programs being pursued by the National Heart Institute.

Materials. At the top of the list is the problem of finding or developing suitable materials to be used in contact with the body fluids and tissues. In considering materials for use in circulatory support devices, it is necessary to understand not only how the material affects the biological system but also how the material itself is affected by the biological environment, fabrication methods, and sterilization techniques.

Controls. In the area of controls, a great deal remains to be learned. If the rather simple approach to satisfying the circulatory demands of the body cannot be met by applying Starling's law of the heart, then some combination of physical, biological, or chemical sensors will have to be developed to provide input signals into a more sophisticated control system.

Attachment. The method of securing the circulatory support system to the body also requires further investigation. From past experience it would appear that direct attachment to the large vessel structures is sufficient to take care of the weight of the blood pump. Other possible supporting structures for anchoring the power source include the rim of the pelvis, the spine, and the rib cage. The final selection of the point and method of attachment will undoubtedly be a function of the weight, volume, and shape of the circulatory support system.

Radioisotope Fuels for Implantable Sources

The use of a radioisotopic energy source in an implantable power supply is especially attractive since it is a highly reliable and predictable form of

energy. The criterions for selecting radionuclides for implantation as energy sources place considerable emphasis on radiation, half-life, and power density. A high power density and a minimum of penetrating radiation help to minimize the radiation dosage, weight, and volume of the unit. A reasonably long half-life is desirable to minimize the frequency of surgery to replace the power source. The principal candidates for implantable energy sources include ^{238}Pu, ^{147}Pm, and ^{171}Tm.

PLUTONIUM-238

Neptunium-237, the precursor of ^{238}Pu, is produced by irradiation of uranium in reactors by the following neutron reactions:

$$^{235}\mathrm{U}(n,\gamma)\ ^{236}\mathrm{U}(n,\gamma)\ ^{237}\mathrm{U} \xrightarrow{\beta} {}^{237}\mathrm{Np}$$

$$^{238}\mathrm{U}(n,2n)\ ^{237}\mathrm{U} \xrightarrow{\beta} {}^{237}\mathrm{Np}$$

Following chemical separation from the uranium, the ^{237}Np is further irradiated in a high-neutron-flux reactor to produce ^{238}Np, which beta decays with a 2-day half-life to ^{238}Pu. Uranium-fueled power reactors offer an excellent source of ^{237}Np. Based on measurements of fuel from existing power reactors, hundred-kilogram quantities will be available annually from power reactors by 1980 (Ref. 5). Plutonium-238 combines a relatively high specific power output with a long half-life (87.5 years). This results in a useful lifetime of greater than 10 years. One gram of pure ^{238}Pu produces approximately 0.56 watt of heat, primarily from alpha decay. The alpha particles do not present a biological hazard problem directly since they deposit their energy over a very short path length and are completely contained within the encapsulating material. The weak photons can be readily shielded.

The shielding requirements for currently available ^{238}Pu fuel are established principally by isotopic and elemental impurities in the product. The isotopic impurities in currently produced conventional ^{238}Pu are:

Isotope	Abundance, %
^{238}Pu	80.0
^{239}Pu	16.5
^{240}Pu	2.5
^{241}Pu	0.8
^{242}Pu	0.08
^{236}Pu	1.2×10^{-4}

The isotopes of plutonium with atomic weights greater than that of ^{238}Pu do not contribute significantly to the radiation flux. They act primarily as a diluent, reducing the energy density of the product. The important isotopic impurity is ^{236}Pu, which is present at a concentration level of about 1 ppm. The decay chain of ^{236}Pu has in it the two important gamma-ray-emitting nuclides ^{212}Pb and ^{208}Tl (Fig. 2). As the ^{238}Pu product ages from the time of purification, these two nuclides "grow in," or increase in abundance. Therefore the amount of gamma activity resulting from these two decay products also increases with time. The gamma-ray shielding requirements are set by the abundance of ^{236}Pu decay products at the end-of-life of the heat source.

Elemental impurities in the ^{238}Pu fuel as currently processed give rise to an enhanced neutron flux from the material. The alpha particles that result from the natural decay of ^{238}Pu interact with the light-element impurities and produce the increase in neutrons. The total number of neutrons arising from these alpha-neutron reactions is directly proportional to the number of light-element impurity atoms present. In currently produced ^{238}Pu the impurity level is such as to cause an order-of-magnitude increase in the neutron flux over the irreducible minimum flux resulting from the spontaneous fission of ^{238}Pu and ^{240}Pu (Ref. 6).

In an effort to reduce the radiation from ^{238}Pu fuel, the AEC has initiated a program to investigate the feasibility of reducing the isotopic impurity levels. A decrease in ^{236}Pu, the critical isotopic impurity, from 1.2 to 0.1 ppm would reduce this problem to one of negligible concern. A study to determine the feasibility and cost of producing large quantities of ^{238}Pu having a low ^{236}Pu content is now under way.

A program to significantly reduce the elemental impurities in ^{238}Pu was also recently initiated. The elemental impurities are removed by an electrorefining process which was originally developed for purifying ^{239}Pu and has been successfully adapted under this program to refine ^{238}Pu. The first batch of electrorefined ^{238}Pu was prepared by Los Alamos Scientific Laboratory during August 1967. Subsequent evaluation of the 11.6-g refined ingot by Los Alamos Scientific Laboratory has established the melting point as 639 ± 2°C, the specific neutron activity as 2250 n/(gram)(sec) [calculated rate for spontaneous fission is 2150 n/(gram)(sec)], and the gamma dose rate as 2.5 mr/hr at 10 cm. The ingot was doubly encapsulated in two 15-mil-wall tantalum tubes. Additional batches of ^{238}Pu will be refined by this technique to determine the optimum procedures and establish the reproducibility of the process. Once the refined ^{238}Pu metal has been fully characterized, other high-purity ^{238}Pu fuel forms will be prepared and evaluated to determine the best fuel form for use in an implantable power source.

PROMETHIUM-147

Promethium-147 is a fission product with a half-life of 2.62 years. It is separated from irradiated fuel in megacurie quantities at Pacific Northwest

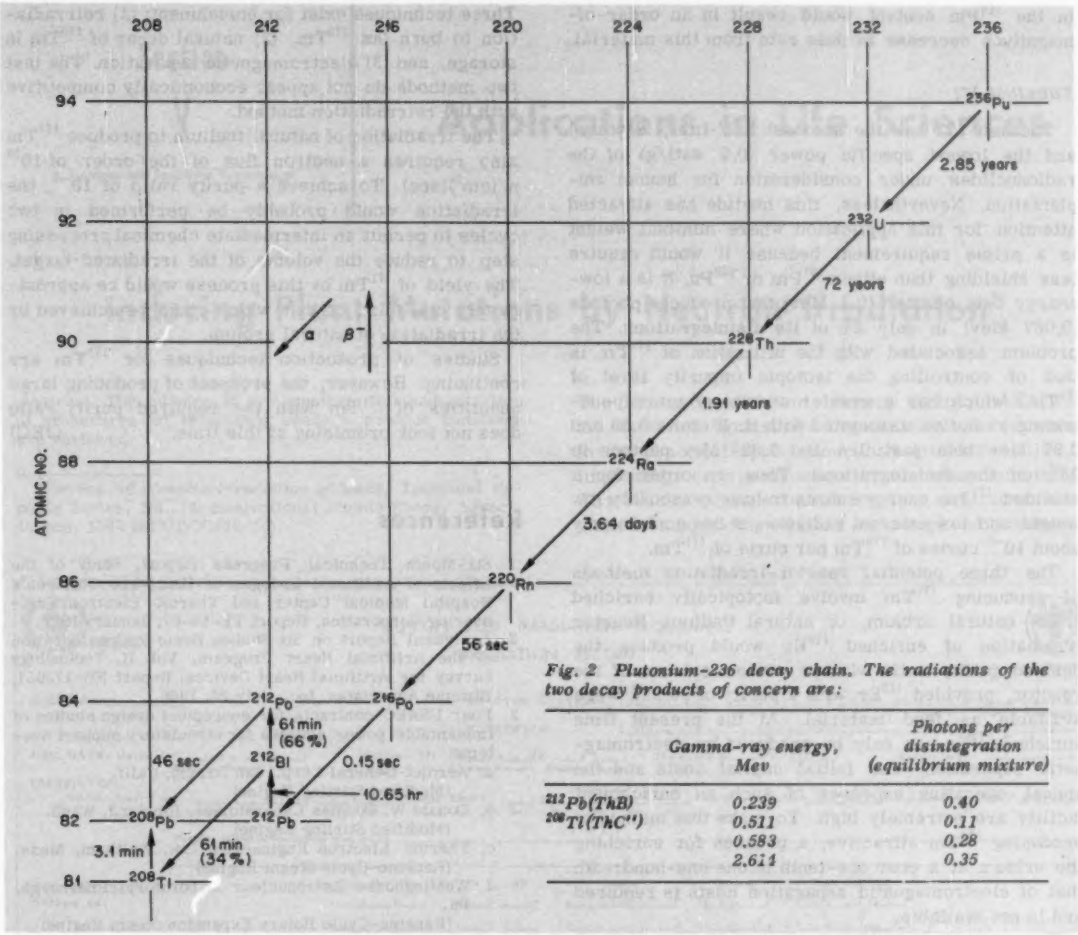

Fig. 2 Plutonium-236 decay chain. The radiations of the two decay products of concern are:

	Gamma-ray energy, Mev	*Photons per disintegration (equilibrium mixture)*
^{212}Pb(ThB)	0.239	0.40
^{208}Tl(ThC'')	0.511	0.11
	0.583	0.28
	2.614	0.35

Laboratory. Approximately 2% of uranium and plutonium fissions yield ^{147}Nd, which decays with an 11-day half-life to ^{147}Pm. Power reactors produce about 3 curies per thermal megawatt-day (based on aging of the fuel for one half-life).

Promethium has a specific power of 0.32 watt/g. Although the half-life of this radioisotope is relatively short, its moderate radiation characteristics make it attractive for use in an implantable power source. The radiation associated with promethium is due to the ^{147}Pm beta emission and bremsstrahlung, the ^{148m}Pm gamma emission, and the ^{146}Pm gamma emission. The soft ^{147}Pm radiation is readily shielded by as little as 0.050 in. of heavy metal. The penetrating radiation from ^{148m}Pm requires heavy shielding. However, because of the short half-life (42 days), significant reduction can be achieved by allowing the material to decay for approximately 2 years following separation. Unfortunately ^{146}Pm cannot be handled in the same way as ^{148m}Pm because of its long half-life (4.4 years). Separation of the promethium isotopes is possible by present technology but appears to be prohibitively expensive.

Consideration has been given to using the differences in neutron cross sections of ^{146}Pm and ^{147}Pm to achieve a reduction in ^{146}Pm content by selective "burnout" in high neutron-flux reactor irradiation. A program has been initiated at the Pacific Northwest Laboratory to evaluate the burnout of ^{146}Pm. Promethium targets with 0.25 ppm ^{146}Pm were irradiated during 1967 and are now in storage to allow the ^{148m}Pm to decay to the point where measurements can be made. Preparations are under way to irradiate promethium from a power reactor (3.5 ppm ^{146}Pm) under various thermal and resonance neutron-flux intensities and for various durations. It is anticipated that a ^{146}Pm-to-^{147}Pm curie ratio as low as 0.01 may be possible on a production scale. Such a reduction

in the ^{146}Pm content would result in an order-of-magnitude decrease in dose rate from this material.

THULIUM-171

Thulium-171 has the shortest half-life (1.9 years) and the lowest specific power (0.2 watt/g) of the radionuclides under consideration for human implantation. Nevertheless, this nuclide has attracted attention for this application where minimal weight is a prime requirement because it would require less shielding than either ^{147}Pm or ^{238}Pu. It is a low-energy beta emitter (0.1 Mev) that produces photons (0.067 Mev) in only 2% of its disintegrations. The problem associated with the utilization of ^{171}Tm is that of controlling the isotopic impurity level of ^{170}Tm, which has a greater amount of more penetrating radiation associated with it. It emits 0.88 and 0.97 Mev beta particles and 0.084 Mev photons in 23% of the disintegrations. Thus, in order for a shielded ^{171}Tm energy source to have reasonably low weight and low external radiation, it can contain only about 10^{-5} curies of ^{170}Tm per curie of ^{171}Tm.

The three potential reactor-irradiation methods of producing ^{171}Tm involve isotopically enriched ^{170}Er, natural erbium, or natural thulium. Reactor irradiation of enriched ^{170}Er would produce the desired purity ratio with an economical use of the reactor, provided ^{170}Er with a purity of 99.99% were available as feed material. At the present time enriched ^{170}Er can only be produced by electromagnetic separation. The initial capital costs and the annual operating expenses of such an enrichment facility are extremely high. To make this method of producing ^{171}Tm attractive, a process for enriching the erbium at a cost one-tenth to one one-hundredth that of electromagnetic separation costs is required and is not available.

The production of ^{171}Tm from natural erbium would require high neutron fluxes of the order of 5×10^{14} to 10^{15} n/(cm^2)(sec). This requirement eliminates the possible use of power reactors. The purity ratio resulting from irradiation of natural erbium would be close to unity; therefore, after the thulium is separated from the erbium target, a final enrichment step would be required to produce a usable product. Three techniques exist for enrichment: (1) reirradiation to burn out ^{170}Tm, (2) natural decay of ^{170}Tm in storage, and (3) electromagnetic separation. The last two methods do not appear economically competitive with the reirradiation method.

The irradiation of natural thulium to produce ^{171}Tm also requires a neutron flux of the order of 10^{15} n/(cm^2)(sec). To achieve a purity ratio of 10^{-5}, the irradiation would probably be performed in two cycles to permit an intermediate chemical processing step to reduce the volume of the irradiated target. The yield of ^{171}Tm by this process would be approximately one-third of that which could be achieved by the irradiation of natural erbium.

Studies of production techniques for ^{171}Tm are continuing. However, the prospect of producing large quantities of ^{171}Tm with the required purity ratio does not look promising at this time. (JEC)

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Section

V

Isotopes and Radiation Technology

Applications in Life Sciences

Inducing Plant Mutations by Neutron Irradiation*

Abstract: The minutes of two meetings on standardization of procedures for irradiating seeds to produce mutations are reviewed.

*Review of *Neutron Irradiation of Seeds*, Technical Reports Series, No. 76, International Atomic Energy Agency, Vienna, 1967 (STI/DOC/10/76).

The International Atomic Energy Agency (IAEA) and the Food and Agriculture Organization are interested in the practical application of neutron irradiation in improving crop production by inducing mutations. The results of experiments on this application from various laboratories cannot be compared because of

IAEA

NEUTRON SEED IRRADIATION PROGRAMME

IRRADIATION RECORD

(PRINT, USING PENCIL)

SHEET No. ____

REACTOR STATION: ____ Name ____ Country ____ Station ____ Reactor No. ____

WORKERS ($): ____

FOIL DATA: Material: ____ Mass No. ____ Element ____ Per cent ____ Diluent: (1) ____ Element ____ Per cent (2) ____ Element ____ Per cent ____ Thickness (mg/cm²): ____ Weight (mg): ____

IRRADIATION DATA: Start Time: ____ Day ____ Mo ____ Yr ____ hr ____ min ____ Stop Time: ____ Day ____ Mo ____ Yr ____ hr ____ min ____ Duration (sec): ____ Reactor Power (MW): ____

Position (distance from reactor core, etc.): ____

COUNTING DATA: Background:

Day	Mo	Yr	hr	min	Counts	Duration	Count Rate (cps)

SAMPLE:

No.	Starting Time Day	Mo	Yr	hr	min	Counts	Duration (sec)	Count Rate (cps)	Count Rate corrected for corresponding background	Elapsed Time t (sec)	Correction Factors for Dead Time	Decay exp.-(λt)	Count Rate corrected to t = 0

Average corrected count rate (cps) at t = 0 ____ Disintegration rate (dps/g) at t = 0 ____

Calibration: Date: ____ Sheet No.: ____ Description: ____

(For Standard Source state origin and physical form, explain in detail)

RESULTS: Cadmium Ratio: ____ Saturation Activity (dps/g): ____ Half life used (sec/min/hr/day/mo/yr): ____

Thermal Flux Density (n/cm² sec): ____ ×10^____ Equivalent Fast Flux Density (n/cm² sec): ____ ×10^____

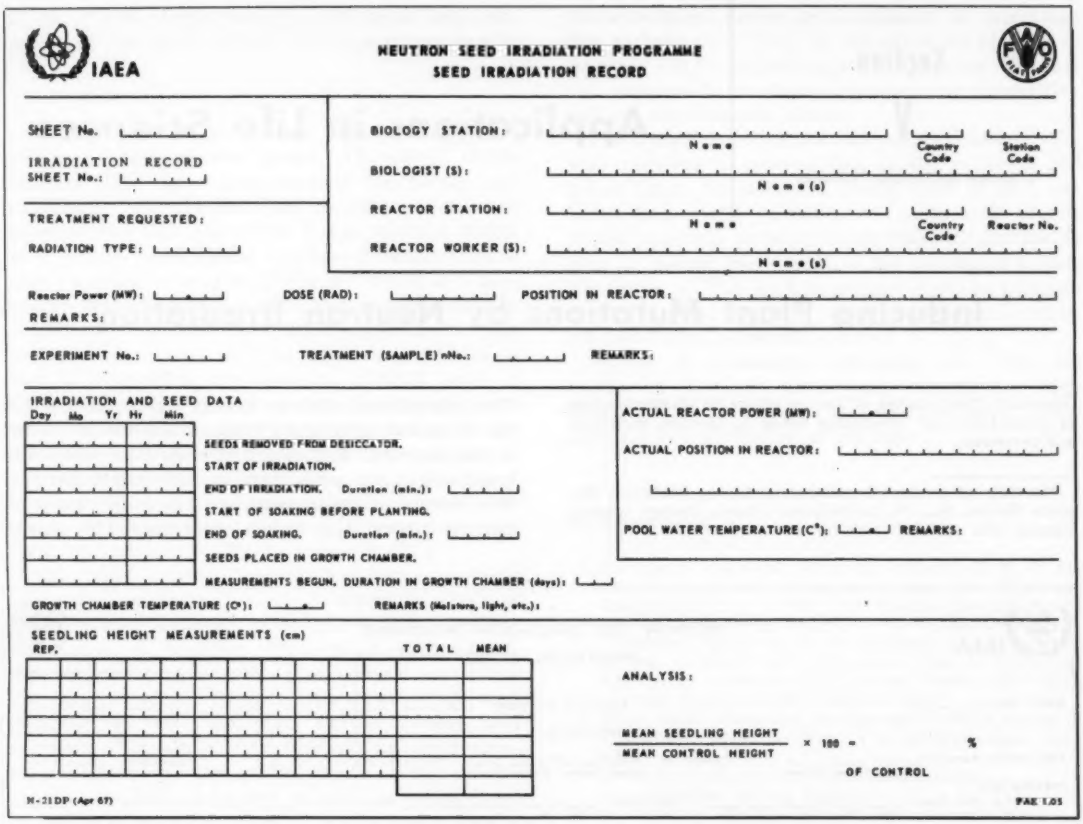
Thermal Fluence (n/cm²): ____ ×10^____ Equivalent Fast Fluence (n/cm²): ____ ×10^____

Cross Section used (b): ____ Cross Section used (mb): ____

REMARKS:

N-10DP (Apr 67) FAE 1.02

Figure 1.



IAEA

NEUTRON SEED IRRADIATION PROGRAMME
SEED IRRADIATION RECORD

SHEET No.

IRRADIATION RECORD SHEET No.:

TREATMENT REQUESTED:

RADIATION TYPE:

BIOLOGY STATION: Name / Country Code / Station Code

BIOLOGIST (S): Name(s)

REACTOR STATION: Name / Country Code / Reactor No.

REACTOR WORKER (S): Name(s)

Reactor Power (MW): DOSE (RAD): POSITION IN REACTOR:

REMARKS:

EXPERIMENT No.: TREATMENT (SAMPLE) nNo.: REMARKS:

IRRADIATION AND SEED DATA

Day Mo Yr Hr Min

SEEDS REMOVED FROM DESICCATOR.
START OF IRRADIATION.
END OF IRRADIATION. Duration (min.):
START OF SOAKING BEFORE PLANTING.
END OF SOAKING. Duration (min.):
SEEDS PLACED IN GROWTH CHAMBER.
MEASUREMENTS BEGUN. DURATION IN GROWTH CHAMBER (days):

GROWTH CHAMBER TEMPERATURE (C°): REMARKS (Moisture, light, etc.):

ACTUAL REACTOR POWER (MW):

ACTUAL POSITION IN REACTOR:

POOL WATER TEMPERATURE (C°): REMARKS:

SEEDLING HEIGHT MEASUREMENTS (cm)

REP. TOTAL MEAN

ANALYSIS:

MEAN SEEDLING HEIGHT / MEAN CONTROL HEIGHT × 100 = % OF CONTROL

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Figure 2.

the differences in techniques used and the paucity of significant details. The meetings whose minutes are reported here were convened to make recommendations on the establishment of an internationally coordinated program of research on neutron seed irradiation, aimed at improving dosimetry and treatment techniques and fostering the use of neutrons for plant breeding. Although reactor neutrons have been used in such work, persons working with radioisotopes are interested in the report because of the possible use of radioisotope neutron sources and the comparison of results with those obtained with gamma-irradiation sources.

As a result of discussions at the meetings, the recommendation was made that all papers reporting research on seed irradiation specify, as a minimum of information, the neutron flux density and spectrum, absorbed dose and dose rate, angular neutron distribution, contaminating radiations, seed composition, and the irradiation facility used (Fig. 1). Members of the IAEA Secretariat presented recommended standard procedures for culturing seeds and measuring the effects of neutron irradiation on seeds (Fig. 2).

Reports made at the meetings contained information on Relative Biological Efficiency (RBE) values of neutron vs. ^{137}Cs gamma radiation for seeds; reactor neutron and radioisotope gamma-irradiation facilities at Brookhaven National Laboratory (United States), Wageningen (Netherlands), and Vinča (Yugoslavia); general dosimetry; objectives of work on specific crops, e.g., sugarcane, wheat, maize, and rice; and the overall seed-irradiation programs in Bulgaria, Denmark, and France. A design study of a facility for fast-neutron irradiation of seeds using a swimming-pool reactor is presented in some detail. Results obtained with barley seeds in an experiment made in the Seibersdorf (Austria) Astra reactor facility to establish basic data needed for this design are described, and details of fast-neutron dosimetry in the Astra are given.

(MG)

Section VI

Isotopes and Radiation Technology

Safety

Report to the Atomic Energy Commission by the Radioisotopes Licensing Review Panel, Sept. 5, 1967

Abstract: A review panel appointed by the USAEC from outside government reviewed the USAEC's policies, procedures, and regulations for licensing and regulating the uses of radioisotopes. Their report, submitted Sept. 5, 1967, concludes that "The Commission's program on the whole has been well conceived and well administered and the Panel has no doubt of its contribution to an excellent health and safety record ..." The Panel indicated that simplification of regulations should encourage more applications of radioisotopes and improve the effectiveness of USAEC's regulatory program. The full text of the Panel's report is given here.

The Radioisotopes Licensing Review Panel, under the chairmanship of George F. Trowbridge, a Washington, D. C., attorney, was appointed in November 1966 to review and appraise the USAEC's policies, procedures, and regulations for licensing and regulating the uses of radioisotopes; to provide the Commission with the Panel's views and conclusions about the effectiveness of these policies and procedures in protecting public health and safety; and to submit recommendations to the Commission for any improvements which the Panel considered advisable. The Panel was requested to give special attention to actions already taken or under consideration by the USAEC for improvement of the radioisotopes licensing program. The report of the Panel was submitted Sept. 5, 1967; it is reproduced here in full for the benefit of the readers of *Isotopes and Radiation Technology* (whose use of radioisotopes will no doubt be greatly affected by the Panel's report).

Introduction

On Nov. 21, 1966, U. S. Atomic Energy Commission Chairman Glenn T. Seaborg announced the appointment of the Radioisotopes Licensing Review Panel. Members of the Panel and their affiliations are listed in Appendix A.

This report has been prepared under the Panel's charter from Chairman Seaborg to:

> Review and appraise AEC's policies, procedures, and regulations for the licensing and regulation of by-product material; provide the Commission with the Panel's views and conclusions as to the effectiveness of these policies and procedures in protecting the public health and safety; and submit to the Commission recommendations for any improvements which the Panel believes should be made. In carrying out this review, the Panel should give special attention to the actions which have been recently taken, or which are under consideration by the AEC, to improve the by-product materials licensing program.

In his remarks to the Panel at the initial meeting on Dec. 6, 1966, Chairman Seaborg asked the Panel to confine its study to the by-product materials regulatory program. Chairman Seaborg also noted that the Panel was not expected to review the Agreement State program, AEC statutory authority, or the basic Federal Radiation Council standards upon which the regulatory program is based, although the Panel's general observations in these areas would be welcome. Export licensing and transportation requirements were also excluded from the Panel's scope of review.

The time required to study the many diverse facets of the radioisotope program—regulations, inspection, enforcement, general and specific licenses, exemptions, and the wide variety of radioisotope uses conducted by more than 8000 AEC licensees—provided a practical limitation on the manner in which the Panel could conduct its 6-month review. The Panel relied heavily on the breadth of its members' own experience, extensive briefings by the AEC regulatory staff, and invitational discussions with nonregulatory AEC staff members and outside experts. In addition, we invited comments and received informal response from the Health Physics Society, the American Nuclear Society, and the Atomic Industrial Forum.

The Panel held nine sessions, most of them 2-day meetings, followed by a 4-day working session for completion of the report. The first four meetings were devoted to detailed briefings by the AEC regulatory staff on all aspects of the radioisotopes regulatory program. The following two meetings included invitational discussions with representatives of the

National Council on Radiation Protection and Measurements, the Federal Radiation Council, the Food and Drug Administration, various nonregulatory AEC divisions, the University of Pittsburgh School of Public Health, and representative schools of thought within the medical profession. The remaining meetings were spent in internal deliberations for preparation of the report.

In its deliberations the Panel had the benefit of certain proposals of the AEC staff to modify its regulatory program. In 1965 AEC established an internal "Tightrope Committee" to review and evaluate its own regulatory program. The Tightrope Committee, headed by Mr. C. L. Henderson, Assistant Director of Regulation for Administration, consists of regulatory-division directors who have formulated recommendations for a series of changes whose broad objectives have found approval within the Panel. Tightrope's recommendations reflect an AEC regulatory philosophy compatible with the Panel's own conclusions.

A list of people outside the AEC regulatory staff who met with the Panel is found in Appendix B. We wish to take this opportunity to express our thanks and appreciation for the remarkable cooperation and assistance of these people.

We are particularly grateful for the able assistance of Mr. Bruce W. Churchill, who served as Secretary to the Panel.

General Conclusions

The Panel has no hesitancy in responding to the Commission's central question as to whether its policies and procedures have been effective in protecting the public health and safety. The Commission's program on the whole has been well conceived and well administered, and the Panel has no doubt of its contribution to an excellent health and safety record.

The Panel's recommendations for improvements are largely in the area of simplifying the regulatory and licensing program. The Panel believes that implementation of its recommendations will improve the effectiveness of the AEC program, not in the sense that there are important gaps to be filled in the protection of the public health and safety, but in the sense that implementation will result in a better and more balanced scheme of licensing and regulation. This in turn will allow AEC, with the same expenditure of effort, to concentrate less attention on regulatory details and to put more emphasis on the central objectives of its regulatory program, i.e., the promotion and, where necessary, the enforcement of sound radiation-protection practices among its licensees. It will increase acceptance of the program by licensees, which in itself is a necessary foundation for effective regulation.

The continued development and more widespread use of radioisotopes is not only highly desirable but also, under proper regulation, entirely compatible with public health and safety. This compatibility has been evidenced by the high degree of radiation safety accomplished under existing AEC regulations. It is this safety record along with the generally increasing competence of licensees that has enabled the Panel to make recommendations aimed at simplifying AEC regulations. Simplification of the regulatory program should encourage more widespread application of radioisotopes and at the same time should improve the effectiveness of regulation.

Because of the diversity of radioisotope uses, the Panel's recommendations to the Commission are also necessarily diverse. We have not thought it useful, therefore, to collect and enumerate in one place all the recommendations dealt with in succeeding portions of this report. However, it is worthwhile to state certain general conclusions that underlie many of our recommendations.

1. The competence of licensees and the availability of radiation-protection information and training, along with the use of radioisotopes, have grown significantly in the past 10 years. It is reasonable today for the AEC to base its regulatory program on the assumption that most licensees can and will develop sound radiation-protection programs designed to meet basic standards promulgated by the AEC.

2. AEC can and should place more emphasis on performance objectives than on the specific procedures and techniques for meeting those objectives.

3. Increased reliance on licensee responsibility and performance objectives is consistent with an effective AEC inspection and enforcement program aimed at determining the effectiveness of the licensee's own safety measures.

4. Guidance to licensees in good radiation practice, in the form of AEC manuals and constructive suggestions by AEC personnel, should receive at least as much emphasis as compliance measures.

5. There is a point at which risks associated with small quantities of radioisotopes become so insignificant that users should be exempted from regulatory control. For these quantities AEC should rely solely on the regulation of manufacturers and distributors to assure proper product design, manufacturing quality control, and product labeling and instructions.

The Panel believes that there is some basis for the common complaint that the regulatory program has been overly legalistic. Enforceable regulations and licensing requirements are an indispensable part of the regulatory program, and there will always be a few licensees who will correct deficiencies in their operations only when enforcement action is taken or threatened. But, in most cases, emphasis on the licensee's own responsibilities for developing safe practices and guidance to the licensee in good

radiation practice will suffice. This approach will produce better results than detailed regulation and licensing conditions.

The Panel arrived at another general conclusion that is peripheral to the scope of its charter. The AEC has been successful in promoting a high degree of radiation safety through its in-house activities, its support of health physics education, and particularly through its regulatory program. However, the Atomic Energy Act provides authority for the regulation of only a relatively small percentage of the sources of potential radiation hazard. AEC's regulatory program has had a positive influence in upgrading generally the level of safety in the use of other radiation sources, but it is our opinion that, on the average, this level is below that for AEC-controlled sources and for sources controlled by Agreement States. We firmly believe that regulation of all sources of ionizing radiation should be conducted according to uniform standards and procedures and (except in areas of special interest, such as ICC control of transportation and FDA regulation of radiopharmaceuticals) under the aegis of a single federal agency. The role of this single agency could be either one of direct regulatory control or of cooperation with state programs, or a combination of both as in the case of AEC's present dual roles in Agreement and non-Agreement States. The Panel did not consider it appropriate to recommend the selection of a particular federal agency for this role.

The panel has found it both logical and convenient to group most of its recommendations under the headings of the numbered parts of AEC's regulations to which they pertain and to discuss these parts in numerical order. Thus the recommendations begin with Part 20, "Standards for Protection Against Radiation," and then proceed in order with each of the regulations in the Part 30–35 series. These are then followed by recommendations with respect to compliance and inspection and a final section on miscellaneous recommendations.

Radiation Protection Standards, 10 CFR 20

Part 20 is the foundation of the AEC regulatory program. In setting out the basic standards that licensees must meet for protection of radiation workers and the public against radiation, it becomes the focal point of the regulatory program for all radioisotope licensees and the public.

Part 20 establishes radiation-protection standards by (1) prescribing limitations on dose received by radiation workers and the public, concentrations of radioactive material in air and water, and levels of external radiation in restricted and unrestricted areas and (2) requiring or prohibiting certain actions for the purpose of promoting good radiation-protection practices and achieving the prescribed limitations. The provisions of Part 20 dealing with posting, surveys, protective clothing, disposal, record keeping and incident reporting all fall in the latter category.

The dose limits are designed to conform to the recommendations of the Federal Radiation Council, which are substantially the same as those of the National Council on Radiation Protection and Measurements. The Panel has not undertaken to comment on the basic quantitative limits of Part 20. We interpret our charter as calling for recommendations dealing only with the type and degree of regulatory control necessary to achieve conformance with the basic standards recommended by the FRC and the NCRP.

In making its recommendations concerning Part 20, the Panel had the following objectives:

1. To give licensees, radiation workers, and the public a better understanding of the rationale and basis for the radiation-protection standards

2. To provide regulations that reflect the present state of the art, i.e., the degree of sophistication of today's licensees, the availability of radiation-protection information, methodology, and training opportunities, and overall awareness of radiation hazards and responsibilities

3. To provide information that is well organized and easily understood by licensees, radiation workers, and the public

4. To provide optimum guidance within the context of Part 20 or elsewhere for licensees in achieving radiation safety without unduly limiting flexibility

The Panel realizes that the accomplishment of these objectives in a single document is no easy task. This is particularly true because Part 20 must also cover reactors, special nuclear material, and source material, as well as by-product material. The general thrust of the Panel's thinking is that, if both the standards and the rationale behind them are presented in a fashion that is not only easy to understand but likely to be read as well, licensees will be better able to achieve the performance standards without being bound by rigid operational requirements. Moreover, removal of detailed operational requirements from Part 20 to nonlegal Manuals of Good Practice, as discussed below, will expand the opportunities for constructive guidance to licensees in addition to simplifying Part 20.

Appendix C contains a number of suggestions for changes in Part 20 too detailed for the body of this report. These include such varied items as the modification of quarterly limits on radiation exposures, establishment of exposure limits on radiation workers rather than in terms of restricted areas, and changes in record keeping and incident reporting requirements.

RECOMMENDATIONS:

1. THE PANEL RECOMMENDS THAT PART 20 INCLUDE A PREAMBLE DISCUSSING THE RE-

LATIONSHIP BETWEEN RADIATION DOSE AND KNOWLEDGE OF BIOLOGICAL EFFECTS. THIS WOULD IMPART PROPER PERSPECTIVE TO REGULATORY LIMITS THAT MAY OTHERWISE APPEAR TO BE A FIXED DIVIDING LINE BETWEEN SAFE AND UNSAFE EXPOSURES.

Because of the importance of Part 20 as the basic source of information for all AEC licensees and the public, it should express the philosophy as well as the standards of AEC's regulatory program. The Panel recognizes that fixed limits on permissible radiation exposures are necessary to a workable and enforceable regulatory program. However, we are also aware that fixed limits are inherently inconsistent with the underlying principles of good radiation-protection practice and with the currently accepted proposition that there is no threshold dose for at least some of the biological effects of human exposure. The principle that radiation exposure should be held to the lowest practicable level is not readily translatable into regulatory codes but, as applied at least to significant exposures, is nevertheless a sound guideline for radiation-protection programs.

In order to impart perspective to its regulatory limits, Part 20 should include an explanation of the principle of acceptable risk as set forth by NCRP and ICRP, or its counterpart, the concept of balancing benefit vs. risk, which has been promulgated by the Federal Radiation Council and which underlies its selection of recommended exposure limits for radiation workers and the general public. Part 20 should explain that, from the standpoint of current medical knowledge, exposures in excess of the limits are not necessarily cause for alarm any more than exposures below the limits are grounds for complacency. As an example, if the permissible annual dose-equivalent were to be set at 5 rems, the receipt of 6 rems in 1 year might do no violence to protection principles, although it would be a formal noncompliance item. On the other hand, and this may be of greater importance, the receipt of 4 rems in 1 year under other circumstances might represent inadequate control.

2. PART 20 SHOULD BE REVISED TO PLACE MORE EMPHASIS ON PERFORMANCE STANDARDS AND LESS ON OPERATIONAL REQUIREMENTS

The Panel recommends the substitution of performance standards for those regulatory requirements which are at present too detailed or too restrictive. For example, the Panel suggests revision of the present elaborate posting and labeling requirements and of the provision which allows licensees to take credit for protective clothing and respiratory equipment only after these have been specifically reviewed and approved by AEC.

The Panel understands and supports the need for a control program rooted in enforceable regulations and license conditions. The use of performance standards is consistent with this need, even though there will undoubtedly be some marginal cases where compliance is more difficult to measure than compliance with detailed technical specifications. Performance standards place the emphasis where it belongs, i.e., on the objectives and end results rather than on the mechanics of radiation-protection programs. Such standards will encourage some licensees to develop innovations and improvements in their programs, leading to a general upgrading of protection measures among other licensees.

Performance standards alone would not necessarily have been appropriate a decade ago when Part 20 was first published. Today, however, licensees are in the habit of meeting the operational requirements of Part 20—for example, the radiation symbol so specifically described in Part 20 is used exclusively, and there is every reason to believe it will continue to be so used even if the description is removed from the regulations to a Manual of Good Practice. The competence of licensees, along with the use of radioisotopes, has grown significantly in the last 10 years. Increasing numbers of schools, industrial licensees, hospitals, and specialized training laboratories are able to offer training in radiation protection; health physics has grown into a recognized profession; and the AEC regulatory program has itself contributed to the education of licensees.

3. THE PANEL RECOMMENDS THAT A SIMPLIFIED PART 20 BE SUPPLEMENTED WITH A SERIES OF MANUALS OF GOOD PRACTICE WHICH PROVIDE GUIDANCE AND OPERATIONAL STANDARDS FOR DIVERSE TYPES OF ISOTOPE USE

With Part 20 redrafted in terms of performance standards, the AEC could notably assist licensees by providing a series of Manuals of Good Practice which would outline operational standards and procedures recommended for achievement of AEC's performance standards. The manuals could be directed toward the various broad categories of isotope use such as research and development, industrial gaging, radiography, medicine, industrial processing, and other appropriate areas. Thus a user of industrial gages, for example, could refer directly to the appropriate manual for guidance on how to achieve the performance standards of the simplified Part 20. The AEC presently has guides published in the areas of industrial radiography, medical diagnosis and therapy and teletherapy. These guides, however, are directed toward assistance in obtaining licenses and should be expanded or supplemented by Manuals of Good Practice.

The Manuals of Good Practice should be in the form of recommended procedures rather than legal requirements. Licensees would be inspected for compliance with the performance standards of Part 20 (and the conditions of their licenses) and would, of

course, be allowed to deviate from the recommendations of the manuals. However, the manuals would serve as a guide, both to the licensees and AEC inspectors, of what AEC considers to be good operating practices.

The manuals should go beyond merely restating the operational standards presently reflected in Part 20. They should include practical details providing guidance to licensees about, for example, appropriate types of personnel monitoring, care and function of film badges, methods of performing leak tests, and the design and use of hoods and glove boxes. An important advantage of the Manuals of Good Practice is that they can be readily updated and revised without going through the rule-making procedure.

4. THE PANEL RECOMMENDS THAT AEC RESPOND PROMPTLY TO SIGNIFICANT CHANGES IN THE PUBLISHED RECOMMENDATIONS OF THE FRC AND THE NCRP.

As long as research continues in the areas of radiation protection and biological effects, Part 20 is likely to become out of date from time to time in such areas as dose terminology and basic exposure limitation. In the present Part 20, for example, no provisions have been made for the ICRP recommendations limiting exposure of pregnant women or the NCRP limits on exposure to minors from educational activities.

Some significant changes that may be proposed from time to time by such authoritative recommending bodies as the NCRP may have a profound influence on working practices or labor–management relations. AEC should initiate prompt study of any such changes. Where possible, an early announcement of the general nature of intended changes would help licensees evaluate and plan appropriate changes in their control systems.

Exempt Consumer Products, 10 CFR 30

Under Part 30 the Commission has exempted from licensing the possession and use (but not the manufacture) of a handful of "consumer products" which contain small quantities of radioactive material and which are intended for use by the general public. Additional applications for exemptions have been pending for some time within the AEC.

In 1965 the Commission published criterions for review and approval of consumer-product exemptions. These criterions call for an evaluation by the Commission, on a product-by-product basis, of each item proposed for exemption and a balancing of the risks of public exposure to radiation against the benefits and usefulness of the product.

On the risk side of the balance, the criterions take into account the dosages likely to be received both by individual users and the population at large in the handling, use, and disposal of the product. On the benefit side the criterions state that products proposed for exemption will, as a general rule, be considered useful to some degree and that the Commission will "normally" not attempt an extensive evaluation of the degree of benefit or usefulness. However, in cases where "tangible benefits" to the public are questionable and the product may have widespread use, the "degree of usefulness and benefit that accrues to the public may be a deciding factor."

Products that successfully meet the test of the criterions are exempted only after going through the Commission's formal rule-making procedure.

The difficulty with the Commission's criterions has been that in practice most, if not all, of the pending applications for exemptions have involved products where the demonstrable benefits and risks have both been so small as to defy measurement and comparison. The difficulty has been compounded by the task of estimating how widespread a use the particular product is likely to have. The effort required of AEC to draw fine balances under these conditions is out of proportion to the consequences to the public safety. The net result has been a prolonged period of inaction by the AEC on pending applications for exemption and the resulting discouragement of new consumer-product developments by industry.

RECOMMENDATION:

THE COMMISSION'S POLICY WITH RESPECT TO EXEMPTIONS OF MOST CONSUMER PRODUCTS CAN BE SIMPLIFIED AND DECISIONS CAN BE EXPEDITED WITHOUT LOSS OF HEALTH AND SAFETY CONTROL. IT APPEARS FEASIBLE AND DESIRABLE, AT LEAST FOR SOME SPECIFIC RADIOISOTOPES, TO RELATE THE BALANCING OF RISKS VS. BENEFITS TO THE TOTAL POTENTIAL USAGE OF A PARTICULAR RADIOISOTOPE RATHER THAN TO INDIVIDUAL CONSUMER PRODUCTS. IN SUCH CASES THE PRESENT RULE-MAKING PROCEDURE SHOULD BE REPLACED BY STAFF DECISIONS ON APPLICATIONS FOR INDIVIDUAL PRODUCT EXEMPTIONS BASED ON GENERAL CRITERIONS ESTABLISHED BY THE COMMISSION.

The AEC has an extremely difficult task in attempting to establish an appropriate balance of benefit vs. risk for consumer-product applications. An individual case may be virtually insoluble because both benefit and risk become vanishingly small. Yet such applications may be precisely those which eventually will lead to broader sensible uses of radioisotope products.

The approach suggested by the Panel does not abandon the principle of balancing benefits and risks. We suggest only that for some classes of consumer products this balance could be drawn on the basis of

total probable benefits and total potential public exposures likely to result from the distribution of all products within the class.

The first step under this new approach would be to make sure that individual products proposed for exemption presented insignificant hazard in normal use and negligible possibilities of injury even under conditions of gross abuse. Products to be exempted should meet the following criterions:

1. Radiation dose to any person from a single or reasonable multiple of such products is insignificant in normal use.
2. The dose to any person will not exceed the annual dose limits recommended for an individual in the general public under conditions of maximum abuse.
3. The maximum release of the contained radioactive material under normal wear and tear is insignificant as a source of radiation or contamination.
4. The manufacturer has clearly demonstrated through performance specifications and quality-control procedures that the above conditions will be met.

The second step would be for the AEC to estimate, for the particular radioisotope in question, the total contribution to radioactivity in the environment which might result from the maximum distribution of exempt products and their ultimate disposal. This step would not call for a refined projection of the expected sales and distribution of existing and potential exempt products. Such projections are neither feasible nor necessary. The Panel does consider it feasible, however, to make an outside estimate of the quantities within a general class of consumer products that could conceivably be distributed within the foreseeable future, using optimistic assumptions as to their commercial development and sale and pessimistic assumptions as to the environmental burden that might result from their use and ultimate disposal. We strongly suspect that even under these assumptions the total burden resulting from exempt products would be extremely small in relation to currently accepted dose limits to the general public.

The third step would be to compare these outside estimates with the total addition to the environment, from all sources, which the Commission considers acceptable for the particular radioisotope in question. Presumably the Commission would arrive at this latter figure in consultation with the FRC. If the maximum estimated burden from exempt products was only a small percentage of the total acceptable addition, AEC would proceed with the exemption of products containing the radioisotope in question if the products otherwise meet AEC's standards for exemption.

Once the Commission has established the general criterions to be met by exempt consumer products and has determined that the maximum estimated burden to environmental radioactivity is acceptable, applications for exemption of specific products would be reviewed and approved at a staff level rather than by Commission rule making.

As a sequel to the adoption of the above program, AEC would require manufacturers to report annually, for each radioisotope, their total sales of exempt products. This would provide a check against AEC's estimate of maximum potential distribution and enable the Commission to reassess its exemption program at 5- or 10-year intervals.

It is convenient to illustrate our proposal in terms of a particular isotope, for example, tritium. Tritium may be firmly incorporated in a wide variety of self-luminous items so that negligible radiation escapes from the item. The maximum abuse might be judged to be the eating of a plausible number of these by a child and the radiation dose shown to be negligible. With proper design and fabrication, abrasion and ordinary wear and tear should occasion negligible releases. Ultimate disposal of the product, even destruction by fire, would release acceptable amounts to the environment.

Compared to the small hazards, it should be readily apparent that the collective benefits of the variety of such products that would be produced are likely to be substantial. The portion of the items for which the benefits measured individually might be argumentative (e.g., dolls' eyes in one observer's opinion, automobile lock illuminators in another's) would be a small fraction of the total.

We are aware that it is not possible to predict within a wide range the probable sales of luminous devices containing tritium assuming a wide exemption of such items. At the same time, even with considerable exercise of the Panel's imagination, it is difficult to visualize in the foreseeable future a sufficiently widespread use of such products that the contribution to environmental radioactivity would be more than a small increment of the tritium inventory to which the general public is already exposed or more than a small fraction of that inventory which the Commission and the FRC would probably consider acceptable.

The AEC may on occasion receive requests to exempt consumer products that, because of the quantities of material involved or for other reasons, do not meet the strict criterions enumerated above. In these cases, individual review of the product and an assessment of the risks and benefits associated with it would continue under the existing AEC criterions.

General Licenses, 10 CFR 31

One of the regulatory techniques used by the Commission is the issuance of "general licenses." The two main categories of general licenses presently in effect are those covering the acquisition and use of small quantities of radioisotopes and those pertaining

to certain devices which have been evaluated by AEC and manufactured or imported under a specific license issued to the manufacturer or importer. (A third category of general license for the use of radiopharmaceuticals in medicine is discussed in the Medical Licensing section of this report.)

General licenses resemble specific licenses in that they authorize the use of specified quantities of radioisotopes, or specified devices containing radioactive materials, subject to restrictions and conditions enumerated in the general license. They differ from specific licenses in that they are addressed to a class of users rather than to individual applicants and that the beneficiaries of a general license need file no application.

General licenses can be a useful and convenient device for avoiding multiple individual licensing actions, where it is not necessary to examine the individual qualifications of each user or circumstances of use but where important restrictions or conditions need nevertheless be applied in the interest of public safety. They are properly used, however, only where the general licensees can be readily identified and their activities can be inspected for compliance with the conditions of the license. If the general licensees cannot be readily identified and the conditions of the license are important to public safety, specific licenses should be used instead. If, on the other hand, the conditions are not important to public safety, the activity should simply be exempted from licensing requirements.

The Panel has applied the above principles to the two main categories of general licenses presently issued by the AEC—general licenses for small quantities of radioisotopes and for certain devices incorporating sealed sources of radioactive materials. The results are reflected in the following recommendations, along with other suggestions relating to the two categories of general licenses.

RECOMMENDATIONS:

1. THE PANEL APPROVES OF CHANGES PROPOSED BY THE AEC STAFF IN THE LIMITS ON SMALL QUANTITIES OF RADIOISOTOPES PRESENTLY GENERALLY LICENSED UNDER §31.4.

The AEC staff has furnished to the Panel a number of proposed changes in the table of quantities, which spells out for specific isotopes the limit on the amount of material which qualifies as a "small quantity." The purpose of the changes is to make the quantity limits for the various isotopes more consistent in terms of comparable exposure risk. Although some limits (e.g., ^{131}I) would be lowered, most of the changes provide for an increase in limits. We believe that these increases can safely be made, and we have taken the changes into account in our next recommendation.

2. SMALL QUANTITIES OF RADIOISOTOPES SHOULD BE EXEMPT FROM THE REQUIREMENTS FOR A LICENSE.

Under the present §31.4, a general licensee may possess 10 small quantities of radioisotopes specified in the table in §31.100. There are no limitations on the chemical or physical form of the isotopes, the packaging or labeling of the isotopes, or the transfer of these small quantities among general licensees. Since there is no reporting requirement for persons who sell or transfer these small quantities, it is not possible for the Commission to identify or to inspect the general licensees. The general licensee is subject to the basic requirements of Part 20, but these requirements are not readily enforceable since the general licensee is not identifiable. Consequently a general license under §31.4 is virtually an exemption.

The Panel does not believe that it is necessary to impose more rigid controls on these small quantities in the interest of public health and safety and therefore recommends that they be exempt from the requirements for a license.

Exemptions for the users of small quantities would not, of course, be inconsistent with controls in the form of specific license requirements on the distributor. The manufacturer could be required to keep records of persons to whom the radioisotopes are distributed and to provide safety information to the purchaser in the packaging and labeling.

The only significant condition that the present §31.4 general license imposes is the prohibition against the accumulation of a large number of small quantities by a single user at a single location. Elaborate measures to discourage such accumulations are not necessary. As a practical matter, sufficient control could be provided by limiting the number of exempt quantities which distributors could sell at any one time to a single individual. Commercial pricing policies will also help discourage multiple purchases of small lots by purchasers who might otherwise try to circumvent the quantity limitations.

The nature of an exemption is such that no legal control is maintained over the radioisotopes once they have been distributed. The small quantities received from licensed distributors could be freely transferred from one exempt person to another. However, the Panel feels that simplified and easy-to-understand labeling information, which would be required prior to the first transfer, would provide a greater degree of overall public safety than is presently provided under the general license.

3. THE PANEL RECOMMENDS THAT ITEMS GENERALLY LICENSED PURSUANT TO §31.3 BE RECONSIDERED BY THE COMMISSION FOR RECLASSIFICATION.

Section 31.3 provides a general license for small quantities of radioisotopes contained in certain static eliminators, spark-gap and electronic tubes, light meters, and ion-generating tubes. Some of these products are widely distributed. The general license applies only to approved devices manufactured under a specific license, but there is no effective AEC control over users of the devices. The general licensees are subject to the requirements of Part 20, but, since there are no other special conditions that attach to the general license, the items can be freely transferred among general licensees, and AEC cannot readily identify and inspect them.

Section 31.3 predates the AEC's present concept of general licenses and exemptions and is inconsistent with it. Since no effective control is exercised over the items once they have been distributed to general licensees, the Panel recommends that they be considered by AEC for reclassification. If AEC determines that the products satisfy appropriate criterions for exemption, then the items should be exempt; if not, they should be effectively controlled under a specific or general license.

For some devices the quantities of by-product material are not insignificant, but a high degree of safety can be engineered into the devices themselves. In such cases the Panel agrees that the Commission has properly placed reliance on licensing and control of the manufacture of the device and that the manufacturer should continue to be the focal point of AEC regulatory control.

4. THE PANEL RECOMMENDS THAT GENERAL LICENSES FOR A NUMBER OF DEVICES, SUCH AS THOSE COVERED BY §31.5, BE CONTINUED IN THEIR PRESENT FORM BUT THAT INDIVIDUAL DEVICES BE PERIODICALLY REVIEWED FOR POSSIBLE RECLASSIFICATION.

Section 31.5 provides general licenses for the use of certain detecting, measuring, gaging, and controlling devices containing radioactive material. Like items generally licensed under §31.3, major reliance is placed on the engineered safety of the device and on control of the manufacturer by specific license. Unlike §31.3, however, the general license carries with it a number of special conditions governing the general licensee's use of the item. He must, for example, have the device installed on his premises by a licensed installer; he is responsible for complying with instructions on the manufacturer's label; he must have periodic leakage tests made by an approved organization; he must report certain failures of the device to AEC; and he cannot transfer the device to other general licensees.

The above conditions, together with the requirement that manufacturers report all sales to the AEC, provide an effective and realistic system of control, and the Panel recommends that this concept of the general license be continued. It is possible for AEC to keep track of the devices and spot-check licensees for compliance with the license conditions. At some future time, however, this general-license concept may no longer be appropriate for some items. It is conceivable, for example, that an item presently licensed under §31.5 might become a common household item. Enforcement of license conditions could then become impractical.

If the potential for widespread use of a generally licensed device develops, the appropriateness of the general license should be reexamined. The Commission might conclude as a result of the reexamination that more realistic controls were necessary, such as permitting manufacturers to lease, but not sell, the device and imposing on the manufacturer instead of the user the burden of compliance with license conditions. Or the Commission might conclude that the device was so well engineered, and that the public benefits so outweighed the public risk, that the device should be transferred to an exempt category.

Specific Licenses for the Manufacture of Exempt and Generally Licensed Items, 10 CFR 32

As previously noted, AEC controls by specific license the manufacture of devices that may then be acquired by the user as an exempt or generally licensed item. Regulations relating to manufacturers' licenses and license applications for these devices are collected in Part 32.

RECOMMENDATIONS:

THE DETAILED QUALITY CONTROL AND PROTOTYPE TESTING REQUIREMENTS FOR LICENSED MANUFACTURERS OF EXEMPT AND GENERALLY LICENSED ITEMS SHOULD BE DELETED FROM PART 32.

Part 32 includes extremely detailed requirements for the prototype testing and quality control of products to be distributed under an exemption or general license. The provisions of Part 32 can be amended only at the Commission level through the cumbersome rule-making process. The Panel feels that there should be more flexibility for changes in Part 32 requirements, particularly as they relate to product variations that may be proposed by manufacturers. We understand that the AEC staff now has authority to exempt licensees from these requirements and on occasion does so. Nevertheless, requirements spelled out in formal regulations may mislead some applicants unfamiliar with exemptions that have been granted and may deter others from proposing different but equally effective controls.

The Panel is aware that the detailed requirements provide useful guidance to manufacturers wishing to

get AEC approval for their products. For this reason the details should be included in a licensing guide which would indicate the AEC standards of approval but which would allow reasonable flexibility without the need of special exemptions.

Broad Licenses, 10 CFR 33

Part 33 provides for the issuance of "broad" licenses, which allow added flexibility to qualified institutions with large research and development programs. The broad license requires the licensee to have a well-qualified isotope committee and gives the committee wide latitude in selecting users, uses, and isotopes without the need for license amendments. The Panel was advised that AEC proposes to extend the broad-licensing concept by amending Part 33 to provide special types of broad licenses for intermediate- and small-sized isotope programs.

RECOMMENDATION:

THE PANEL ENDORSES THE STEPS PROPOSED BY AEC TO EXTEND THE BROAD-LICENSING CONCEPT TO A GREATER NUMBER OF LICENSEES.

The AEC staff has described to the Panel three types of broad licenses. The AEC's proposed type A broad license for large institutions would be essentially the same as the existing broad license except for increased scope in the types of use authorized (such licenses could authorize teaching, processing for distribution, industrial processes, or commercial services as well as research and development) and increased emphasis on the responsibility of management. A new type B license would be similar except that the isotope possession limit would be smaller and the functions of the isotope committee could be performed by a single well-qualified radiological safety officer. A new type C broad license for small programs would have even lower possession limits and would prescribe training and experience for the individual users rather than requiring the licensee to have an isotope committee or a radiological safety officer.

The broad licenses proposed by AEC are not intended to supplant entirely the present types of specific licenses, but are intended to allow greater flexibility to especially qualified licensees, large and small. This proposed revision of Part 33 is in keeping with the Panel's view that the Commission's licensing activities should not only place increased reliance on the training and experience of the licensee's personnel to conduct licensed programs safely but also afford the licensee as much freedom in conducting his program as is consistent with public health and safety.

The wider use of the broad-license concept will require increased reliance on the quality of inspectors and inspection procedures for determining the adequacy of a broad program. Although we feel it desirable in the interests of national uniformity that Agreement States follow suit on Panel recommendations adopted by AEC, it does not necessarily follow that Agreement States should be encouraged to adopt this recommendation before they have inspection personnel sufficiently trained and experienced to provide the expertise necessary to exercise sound judgment in evaluating broad programs.

Industrial Radiography, 10 CFR 34

The AEC program for licensing industrial radiography has had a highly beneficial effect on radiation safety, including the indirect promotion of improved handling of radiographic sources (X rays and radium) outside AEC jurisdiction. Nevertheless, the number of avoidable overexposures in industrial radiography gives cause for continuing concern.

The reason for these overexposures is not entirely clear. Mechanical defects and operator inattention to good practice seem to combine to contribute to the situation. Major contributing factors may be the reported prevalence of part-time radiographers, as compared to those fully trained, and to the particular pressures of field work, often in remote locations.

Licensing and operational requirements for industrial radiography are more detailed than those for any other category of radioisotope use. There are quite specific requirements for training of radiographers as well as detailed step-by-step procedures. In this particular area of isotope use, we do not feel that the trend of our recommendations in other areas toward performance standards with decreased emphasis on detailed operating requirements is applicable. Existing requirements appear reasonable in view of the nature of the radiography industry.

RECOMMENDATIONS:

1. THE AEC SHOULD REQUIRE IMPROVED DESIGN AND FABRICATION STANDARDS AND PERIODIC INSPECTION BY THE LICENSEE OF HIS EQUIPMENT TO REDUCE THE NUMBER OF OVEREXPOSURES DUE TO MECHANICAL FAILURE.

A significant percentage of reported radiography incidents have been the result of mechanical failure of radiography-exposure devices. The AEC has no information about the number of times potential incidents from mechanical failure were avoided by proper adherence to established operating procedures.

Most mechanical failures are associated with the source-and-drive cable assembly: separation of the source from the drive cable, break in the cable, false reading of the source-position indicator, or a combination of these. The Panel believes that the number

of incidents from these types of mechanical failures would be reduced with the development of a fail-safe indicator of source position, with the development of a standard, highly reliable assembly for connecting the source to the cable, and with a requirement for periodic maintenance and inspection of the equipment.

2. THE PANEL STRONGLY URGES AEC TO EXAMINE THE FEASIBILITY OF LICENSING INDIVIDUAL INDUSTRIAL RADIOGRAPHERS.

Part of the difficulty in minimizing overexposures is due to lack of adequate assurance of the competence of the operators and lack of incentive for the operators to follow safe practices.

Standards of training and competence should be established for operators, and only licensed personnel should be allowed to operate the devices. Evidence of negligence or incompetence on the part of an operator should be cause for revocation or suspension of his license. This would result in the development of a professional attitude among operators.

The Panel recognizes that this would be a large undertaking but is of the opinion that the reduction of serious overexposures would justify the necessary investment.

Medical Licensing, 10 CFR 35

The AEC currently regulates the use of by-product material in humans by evaluating (1) the efficacy of the radioactive compound and patient safety; (2) the radiation-safety aspects of the licensee's program with respect to the health and safety of radiation workers and the public; and (3) the training and experience of physician users, both in the clinical use of radiopharmaceuticals and in general radioisotope-handling techniques.

The AEC licensing requirements depend on the type of human use and the stage of development of the clinical procedure. This can be broken down as follows:

A. Investigational Uses

1. Research—radioactive compounds administered to obtain biomedical information about body functions or the manner in which a compound is metabolized. These studies are not intended to develop a procedure for clinical diagnosis or therapy and are often designed and performed on a short-term "one-shot" basis.

2. Developmental—radioactive compounds administered for the purpose of developing and evaluating the efficacy of a new procedure for clinical diagnosis or therapy. Although these studies are usually initiated and developed in a single university or hospital, the more promising of them are subsequently conducted in many institutions throughout the country, particularly if drug manufacturers assume a sponsorship interest.

B. Routine Uses

Diagnostic or therapeutic uses of radiopharmaceuticals for which efficacy and patient safety have been well established. They are no longer considered investigational and are used "routinely" by physicians in hospitals and private offices.

*Applications submitted for investigational uses, whether research or developmental, must be accompanied by a protocol containing information on the safety and efficacy of the drug and a detailed plan of investigation that enables the AEC to determine that the investigation will not present an undue hazard.**

Applications for uses considered routine by AEC do not require a research protocol and are not usually sent to AEC's Advisory Committee for review. The AEC reviews the clinical training and experience of these applicants, but the requirements are less demanding than those for investigational uses.

When the Food and Drug Administration's regulations for investigational new drugs (21 CFR §130.3) became effective in early 1963, a temporary exemption was included for radioactive drugs regulated by AEC. In practice, the FDA exemption covers both investigational and routine uses. The exemption was granted so that (1) the staffs of AEC and FDA could adjust and coordinate their respective regulatory programs with a minimum of duplication and (2) manufacturers and investigators could then modify their programs in an orderly manner to conform to FDA regulations.

The FDA has indicated to the Panel its intention to withdraw in the near future the exemption of radiopharmaceuticals controlled by AEC. The Panel commends AEC for the manner in which it has both regulated and encouraged the use of radioisotopes in medicine. At the same time the Panel agrees that FDA should in due course assume regulatory responsibility for the safety and efficacy of radioactive drugs. As radiopharmaceuticals become increasingly numerous and complex, there is an increasing need for regulation of the manufacturing and nonradiological safety aspects of these drugs by FDA. However, this transfer of responsibility should occur in a manner that will not disrupt either the development of new medical applications of radioisotopes or the clinical use of those already approved by AEC as routine.

The Panel has studied the FDA as well as the AEC regulatory programs for the purpose of making recommendations concerning the AEC program as it

*This determination may be made by AEC with the assistance of its Advisory Committee on Medical Uses of Isotopes. Most investigational studies are, however, conducted under broad licenses, and the investigational proposal is submitted for approval to the licensee's own isotope committee rather than to AEC's Advisory Committee.

might be conducted after FDA removes the radiopharmaceutical exemption. On the basis of our own observations and discussions with representatives of AEC, FDA, and the medical profession, we feel that AEC should relinquish control over the patient-safety aspects of the administration of by-product materials to humans as other and more traditional regulatory mechanisms become available, while retaining responsibility for the health and safety of radiation workers and the public.

The Panel believes that FDA should be responsible for evaluating drug safety and efficacy and that the medical profession should be responsible for the professional competence of physicians to administer radioactive materials to humans. The AEC evaluation of physician competence has acted inadvertently to deter the normal development by the medical profession of its own standards of competence in this field. However, the medical societies are now moving to establish a board of nuclear medicine examiners, and nuclear medical techniques are increasingly taught in medical schools and in postgraduate training courses. With the medical community placing increased emphasis on training and competence, we believe that in due course most AEC licenses issued to physicians will fall into two main categories: (1) broad licenses issued to physicians certified by a board of nuclear medicine examiners and (2) general licenses issued to any physician permitting him to perform most routine diagnostic procedures.

RECOMMENDATIONS:

1. WHEN THE CURRENT FDA EXEMPTION IS CANCELED, THE PANEL RECOMMENDS THAT THE AEC RELINQUISH ITS RESPONSIBILITIES FOR EVALUATING EFFICACY AND PATIENT SAFETY FOR BOTH RESEARCH AND DEVELOPMENTAL USES OF RADIOISOTOPES IN HUMANS.

Although FDA personnel have had little experience with radioisotopes, they have had extensive experience in drug-manufacturing technology and are expert in evaluating sterility, pyrogenicity, purity, and other aspects of good manufacturing practices. They are experienced in evaluating the toxicity and pharmacology of new drugs, and they have worked closely with the pharmaceutical manufacturers to establish effective protocols for the evaluation of efficacy. Complex radiopharmaceuticals now constitute the majority of radioactive compounds used in clinical practice. It seems reasonable, therefore, to have these newer agents evaluated by an agency with expertise in pharmaceutical-manufacturing techniques. However, the Panel considers it essential that FDA assure itself of competence in patient radiation safety.

Research and developmental studies involving radiopharmaceuticals would be controlled by FDA under its investigational new drug (IND) regulations in 21 CFR §130.3. Since the IND regulations look to the safety and efficacy of pharmaceuticals and since dual regulation is inherently undesirable, AEC should cease to evaluate the safety of the patient receiving the investigational radiopharmaceutical when FDA has assumed this responsibility.

2. AUTHORIZATIONS FOR USES OF RADIOPHARMACEUTICALS PRESENTLY APPROVED BY AEC AS ROUTINE SHOULD BE CONTINUED PENDING APPROVAL BY FDA OF NEW-DRUG APPLICATIONS FOR SUCH USES.

If FDA were to cancel the exemption for AEC controlled radioisotopes, radiopharmaceuticals now approved by AEC for routine use could no longer be commercially distributed unless and until new-drug applications had been approved by FDA. The Panel is not aware of any evidence contraindicating the continuation of present routine uses. Since it will take time for drug manufacturers to file and for FDA to process new-drug applications, the sudden withdrawal of FDA's exemption could bring an intolerable halt to many of the most promising and beneficial applications of nuclear medicine. The Panel strongly recommends that any withdrawal of the exemption include a "grandfather" clause permitting the continuation of routine drug uses until FDA has approved new-drug applications currently pending before FDA or actively under preparation by drug manufacturers.

Once new-drug applications have been approved by FDA, the Panel sees no need for AEC review either of the drug or its use from the standpoint of patient safety. Patient safety will be adequately protected through FDA's own review of new drugs and the instructional material that must accompany new drugs under FDA labeling requirements.

3. THE PANEL RECOMMENDS THAT THE GENERAL LICENSE FOR MEDICAL USE BE EXPANDED TO INCLUDE MORE RADIOPHARMACEUTICALS APPROVED BY AEC FOR ROUTINE DIAGNOSTIC PURPOSES AND HAVING AN EFFECTIVE FDA NEW-DRUG STATUS. TO MAKE THE GENERAL LICENSE USEFUL, AEC SHOULD ALSO ESTABLISH REALISTIC POSSESSION LIMITS.

The expansion of the general license would stimulate the use of nuclear medical techniques as diagnostic screening procedures: The general license, with its registration requirement, would permit AEC to fulfill its mandate to protect the public and radiation workers by ensuring sound radiation-safety practices through periodic inspections. Also, proper use of radiopharmaceuticals would be fostered by the detailed instructions included with all FDA-approved materials.

The present general license for human use has not proved of significant benefit to the medical profes-

sion. Drug manufacturers have made little effort to obtain the NDA's which Part 32 requires because possession limits are too low to permit a meaningful nuclear medicine program. We believe that these possession limits can be increased, at least by an order of magnitude, without significantly increasing radiation-safety problems and that this should be done so as to make the general license useful. The ultimate goal should be general licensing of all radiopharmaceuticals approved by AEC and FDA for routine diagnostic use.

4. THE PANEL RECOMMENDS THAT AEC PROGRESSIVELY REDUCE ITS ROLE IN THE EVALUATION OF THE COMPETENCE OF PHYSICIANS TO PRACTICE NUCLEAR MEDICINE AS STANDARDS OF COMPETENCE ARE ESTABLISHED BY THE MEDICAL PROFESSION.

The AEC licensing of physicians to perform specific medical procedures is unique; in all other instances the basic control of medical practice is by regulation from within the medical community. The Panel therefore recommends that AEC work actively with appropriate branches of the medical profession to promote the early establishment of some form of examining board in nuclear medicine that would certify competence in all aspects of the use of radioactive materials. Board certification will result in a higher level of competence than is currently necessary to meet AEC licensing requirements and should be accepted by AEC as prima facie evidence of the physician's qualifications.

We recognize that there will be physicians who will want to use radiopharmaceuticals but who will not take nuclear medicine board examinations. The AEC would continue to pass on the competence of these individuals who apply for specific licenses. However, with the recommended expansion of general licenses for medical use (where physician competence is not examined) and the use of institutional broad licenses (where competence is judged by the licensed institution), AEC's role in the examination of physician qualifications, even in the absence of board certifications, will diminish.

5. THE PANEL RECOMMENDS THAT AEC EXPAND ITS PROGRAM OF BROAD LICENSES FOR MEDICAL DIAGNOSIS, TREATMENT, RESEARCH, AND DEVELOPMENT.

Broad medical licenses have been issued to institutions with extensive radioisotope programs. The Panel believes that categories of broad licenses similar to those proposed by the AEC staff for nonmedical uses of radioisotopes can appropriately be applied to medical programs conducted by both institutions and individual physicians. This would enable the use of broad licenses by qualified physicians in small institutions or in private practice.

We envision the following licensing scheme as feasible under our medical licensing recommendations:

A. The present broad medical license should be encouraged for large medical institutions. The broad license would authorize the licensee's isotope committee to evaluate the qualifications of physicians and the use of isotopes in research and developmental studies conducted under FDA regulations.

B. A broad license of more limited scope and with lower possession limits could be issued to qualified physicians in smaller institutions or in private practice. The license would authorize the physician to perform all routine uses, diagnostic or therapeutic, and any developmental studies conducted under FDA regulations. The AEC would evaluate each physician's training and experience to determine if he is qualified for such authorization. We believe that a higher overall level of competence in the field of nuclear medicine will result if the medical profession provides certification that would satisfy the training and experience requirements of this type of broad license.

C. The Panel is in full agreement with the AEC's medical-class license proposal,* which provides that AEC will issue a license for all of a group of routine diagnostic procedures to qualified applicants. The medical class license should be adopted as soon as possible as an interim measure until Recommendation No. 3 above becomes effective. The use of the class license would gradually decrease as routine diagnostic pharmaceuticals become approved by FDA and eligible for the general license.

D. Physicians and institutions outside the above categories would continue to be licensed on a case-by-case basis.

Inspection and Enforcement

Enforcement of AEC regulations and license conditions is accomplished through periodic inspections and special investigations of licensees, followed by compliance actions that range from simple notifications to formal revocation proceedings.

Inspections are conducted out of five regional offices of the Division of Compliance by AEC inspectors with an average of 9 years' experience in health physics. Nearly all have science or engineering degrees at the bachelor or master level.

Licensees are inspected on a priority system based on the potential hazards associated with the various types of isotope use. The priority system, which presently ranges from 3 to 12 inspections per year for major facilities all the way to a 5% yearly sampling of certain limited industrial users, is continuously under review by the Division of Compliance

*Published for public comment in the *Federal Register*, 31(216): 14317 (Nov. 5, 1966).

and modified as indicated by statistical compilations of inspection results. The priority assigned to a given licensee depends on the type of radioisotope program and his past inspection record.

Enforcement is achieved through a sequence of actions which depend on the severity of the items of noncompliance found during the inspection. The licensee is informed on the spot of minor and readily correctible items, with no additional AEC action before the next regularly scheduled inspection. If items of more than minor significance are found, the licensee is informed in writing, and his written reply is evaluated by the Director of the Regional Compliance Office. If management's written response indicates adequate corrective action, a reinspection is scheduled for verification of the corrective action. An important aspect of the inspection program is a discussion of findings with licensee management at the conclusion of each inspection.

If adequate corrective action of noncompliance items is not indicated in the licensee's response or subsequent reinspection, the items are referred to Washington for formal enforcement action. In addition, items of unusual severity, immediacy, or complexity are referred directly to Washington for formal enforcement action. Such actions may include written notification to licensees and evaluation of the replies, special investigations, modification of licenses, suspension of licenses, or revocation of licenses.

RECOMMENDATIONS:

1. THE PANEL RECOMMENDS THAT AEC'S INCREASED EMPHASIS ON QUALITY OF INSPECTORS AND INSPECTION PROGRAMS BE CONTINUED.

The Panel found wide agreement among licensees that the AEC inspection program has substantially improved in the last 3 or 4 years. This is due in part to AEC's commendable emphasis on the quality of inspectors and inspection programs. Emphasis has been directed more toward substance and technical adequacy of radiation-protection programs than on compliance with peripheral requirements such as posting and records. This change of emphasis has in turn led to increased acceptance of, and respect for, the entire regulatory program by licensees. The informal notification procedure for minor and readily correctible items of noncompliance illustrates the change of emphasis.

The competence and judgment of AEC inspectors would become even more important under the Panel recommendations for (1) increased use of the broad license with the related dependence on the licensee for the development of sound management procedures and the details of his own radiation-protection program and (2) increased emphasis on performance standards in AEC regulations.

The Division of Compliance should continue its practice of continually reviewing the apportionment of inspection effort with a view to ensuring that maximum attention be paid to matters of real health and safety concern. Licensees who are repeatedly found to have significant items of noncompliance should receive special attention to whatever extent necessary to achieve lasting corrective action.

2. THE AEC INSPECTORS SHOULD BE PERMITTED AND ENCOURAGED TO USE THEIR OWN DISCRETION IN MAKING CONSTRUCTIVE SUGGESTIONS TO LICENSEES ABOUT THEIR RADIATION-PROTECTION PROGRAMS.

Apparently there is mixed opinion within AEC as to how much advice, if any, AEC inspectors should give licensees. On the one hand, AEC inspectors, by virtue of their training, familiarity with radiation practices, and knowledge of AEC requirements, are in a unique position to give helpful suggestions to licensees. On the other hand, the Panel recognizes risks entailed in this recommendation and realizes the likelihood that advice may at times be misunderstood. In extreme cases inspectors may be accused of usurping the functions of private consultants or of pressuring licensees to adopt measures not required by AEC.

On balance, however, we believe that the central objective of the AEC regulatory program—sound radiation-protection practices—will be decidedly better served by encouraging inspectors to give advice to licensees.

Miscellaneous Recommendations

The following comments apply generally to the regulatory program:

1. THE PANEL RECOGNIZES THE INHERENT BENEFITS OF THE AGREEMENT-STATE PROGRAM BUT IS CONCERNED THAT UNDUE PROMOTION MAY CAUSE SOME STATES TO ENTER INTO AGREEMENTS BEFORE THEY ARE ADEQUATELY PREPARED TO PROTECT PUBLIC HEALTH AND SAFETY.

Although AEC regulation is limited by law to reactor-produced radioisotopes, Agreement States have generally expanded their regulatory programs to encompass other sources of radiation, such as radium and X-ray machines. The ability of Agreement States to regulate all forms of radiation and to provide closer contact with licensees has proved to be a highly desirable by-product of the Agreement State program. There is, however, some indication of a tendency for the AEC staff to "oversell" states on entering into agreements, perhaps before the states have the administrative and technical capabilities for sustaining an adequate health and safety program. The Panel urges caution in this regard.

Several of the Panel's recommendations for simplifying and streamlining the AEC's regulatory program for by-product material are considered to be contingent on the availability of a high degree of technical competence in the regulatory staff. If these recommendations are accepted by AEC, it is anticipated that Agreement States will follow suit. The Panel has some concern as to the ability of the Agreement States to obtain and maintain a level of technical competence equivalent to that of the AEC staff. Thus we would urge that AEC assure itself of the adequacy of a state's capabilities before entering into an agreement and take all feasible steps to ensure that such capabilities are maintained after an agreement is in force.

2. PUBLIC EDUCATION PROGRAMS TO ALLAY UNWARRANTED PUBLIC APPREHENSION OF RADIOACTIVITY ARE VERY IMPORTANT AND SHOULD BE GIVEN GREATER EMPHASIS.

Public apprehension about anything having to do with radioactivity has abated somewhat in the last few years. However, there still exists a degree of sensationalism in the press and some startling exaggerations in popular television programs. The Panel believes that greater efforts are necessary to place radioisotope use in proper perspective.

The Panel was impressed with AEC's public information program in the area of educational films but urges AEC to expand its efforts in other areas of public education.

3. THE REGULATORY PROGRAM WOULD BE BENEFITED BY ENCOURAGING AEC WASHINGTON-BASED PERSONNEL TO MAKE MORE FREQUENT VISITS TO LICENSEES' FACILITIES.

One of the advantages of an Agreement State program is the opportunity for frequent contact between regulator and licensee. Both can benefit when field visits are made not only by inspectors but also by personnel responsible for the issuance of regulations and licenses. Periodic visits to licensees can help to maintain staff perspective of the practical radiation-safety problems involved.

4. INFORMATION DERIVED FROM SIGNIFICANT ITEMS OF NONCOMPLIANCE SHOULD BE CONSTRUCTIVELY USED TO IMPROVE LICENSING PROCEDURES AND PRACTICES.

The AEC Division of Compliance collects statistics on items of noncompliance, including incidents, found both in their own inspections and in those of the Agreement States. The data so collected are used in determining inspection priorities and sometimes in formulating licensing policies. There is, however, apparently no formal AEC program for systematically analyzing information obtained in inspections and incident investigations for the purpose of initiating broad improvements in regulations and licensing policies. We believe that such a program would contribute to long-range effectiveness of the regulatory program.

5. EXAMINATION AND APPROVAL OF THE DESIGN AND FABRICATION STANDARDS OF SOURCES AND DEVICES EMPLOYING BY-PRODUCT MATERIAL THAT A MANUFACTURER PROPOSES TO DISTRIBUTE SHOULD BE PERFORMED CENTRALLY RATHER THAN BY INDIVIDUAL STATES.

Most sealed sources and devices are evaluated by AEC from information submitted by the manufacturer. This facilitates the processing of applications later submitted by the manufacturer's customers for use of the sealed sources and devices.

The establishment of the necessary competence to properly evaluate the safety and limitations of proposed designs of sources and devices is an imposing task. It seems difficult and redundant to do this in each Agreement State as well as in AEC. We believe that relegating this task to AEC for all such items will result in a more efficient utilization of the nation's skills and resources while at the same time ensuring better protection for the public against marginal or submarginal designs. As the isotope industry matures, this function might ultimately be assumed by a central industry-sponsored laboratory or by an independent testing laboratory.

Licensing of the manufacture and use should remain a function of the Agreement States or, if the licensee is not located in an Agreement State, of the AEC.

6. THE AEC SHOULD ENCOURAGE A LICENSING PROCEDURE WHEREBY APPLICANTS SUBMIT INFORMATIVE DESCRIPTIONS AND PROCEDURES OF WHICH ONLY THE BASIC PROTECTION PRINCIPLES BECOME BINDING LICENSE CONDITIONS.

In issuing specific licenses, AEC relies on the information the applicant has submitted to describe his radiation program. Most licenses contain a condition that incorporates such information in the license. This means that even the experienced licensee is not free to modify details of his radiation program to meet his day-to-day needs without applying for an amendment or risking a citation for violating a condition of his license. This may not present a problem for most specific licensees, but large, diverse programs may be unduly handicapped.

In accordance with the Panel's view that increased freedom of action should be granted where warranted by the licensee's training and experience, we recommend that AEC adopt a procedure of binding the licensee only to those parts of the application which are fundamental to the safety of the program.

We do not intend that AEC assume the task of sorting out the important points in each application and referencing them in the license. The AEC could let it be known that applications could be filed with the basic standards and descriptions set apart from the descriptive details which could be varied at the discretion of the licensee. This would encourage licensees to provide comprehensive information upon which the safety of the operation can be determined and still allow the licensee to make minor day-to-day changes and improvements without filing for a license amendment.

For some classes of licenses, it may be possible for AEC to provide standard forms that upon completion constitute the mandatory section of the license. An attached descriptive portion provided by the licensee would be helpful to the AEC staff in evaluating the license, without being binding in detail on the licensee.

7. THE AEC SHOULD CONTINUE ITS CURRENT PRACTICE OF WIDENING LICENSE AUTHORIZATIONS IN OBVIOUS SITUATIONS WHERE THE APPLICANT HAS UNNECESSARILY RESTRICTED HIMSELF.

Licensees often fail to request authorization in certain areas where AEC, with its years of licensing experience, can see that a license amendment will almost inevitably be needed and can be issued without the need for additional health and safety information. For example, teletherapy and industrial radiography applicants often overlook the fact that they will actually possess two sources during the short interval when their sources are exchanged; AEC routinely provides coverage for both sources even though only one was requested. Another example might be in the laboratory that requests authorization for isotope studies in rats; it could just as easily be licensed to work with all kinds of small laboratory animals without sacrificing public health and safety.

The Panel recommends that AEC continue its general policy of anticipating such obvious needs and broadening authorizations when consistent with good radiation safety. Also, the published guides on how to obtain licenses in various categories could usefully contain hints on avoiding unnecessarily restrictive licenses.

8. IT IS IN THE INTEREST OF THE REGULATORY PROGRAM TO ACCELERATE EACH STEP OF THE LICENSING PROCESS.

The Panel has received some complaints about the length of time it takes AEC to respond to license applications. We believe that some of the recommendations contained in other sections of this report for simplifying licensing procedures will help to avoid licensing delays.

Appendix A

MEMBERS OF RADIOISOTOPES LICENSING REVIEW PANEL

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Appendix B

PANEL GUESTS

The Panel wishes to express its thanks and appreciation for the cooperation of the following individuals outside the AEC regulatory staff who met with the Panel at its request:

Dr. Lauriston S. Taylor, President, National Council on Radiation Protection and Measurements

Dr. Paul C. Tompkins, Executive Director, and Mr. Claire Palmiter, Federal Radiation Council
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Appendix C

SPECIFIC RECOMMENDATIONS ON PART 20

In its general recommendations covering Part 20, the Panel feels that greater emphasis should be placed on performance standards and that many of the detailed operational requirements should be removed to Manuals of Good Practice. The following list of specific recommendations for changes in Part 20 illustrates the goals of the general recommendations. The suggestions are of varying importance; they are listed in the order of their sequence in Part 20.

§20.3 *Definitions.* 1. "Restricted area" is reasonably defined in this section, but the Panel does not believe that the concept of a restricted area should be used as the basis for defining permissible exposures. The essential distinction should be made in terms of the individual rather than a broadly defined area that often includes people who are not occupationally exposed to radiation. People whose duties are unrelated to radiation, but who happen to work in what the licensee has chosen as his restricted area, should not be permitted to receive the same exposure allowed for radiation workers.

Accordingly the Panel recommends that the definitions of "restricted area" and "unrestricted area" [§§20.3(*a*)(14) and (17)] be deleted and that §20.3(*a*)(10) be replaced with a definition along the following lines: " 'Occupational exposure' means exposure of an individual to ionizing radiation in the course of employment in which the individual's normal duties or authorized activities necessarily involve the likelihood of exposure to ionizing radiation."

The Panel did not attempt a detailed revision of other sections of Part 20 to conform to this revised concept but believes that it is feasible to do so. Such a change would not preclude a licensee from establishing restricted and unrestricted areas for his own internal control purposes.

It should be noted also that this proposal would not alter the notion or the definition of "radiation areas" and "high radiation areas."

2. The definition of "calendar quarter" consists of 299 words and is detailed far out of proportion to the significance of this time interval to sound radiation protection. Licensees should be permitted to adopt any method of calculation which reasonably approximates a calendar quarter and which is consistent with the licensees' own recording and record-keeping intervals.

3. Some confusion would be eliminated if all definitions were included or referenced in alphabetical order in this section.

§20.4 *Units of Radiation Dose.* The definitions of dose and dose units should be updated to conform with the recommendations contained in paragraphs 10 through 21 of ICRP Publication No. 9. This includes defining the term "dose-equivalent" rather than "dose" to be used in conjunction with the rem and using modifying factors such as a quality factor (QF) in lieu of the present conversions from rads to rems.

§20.101 *Exposure of Individuals to Radiation in Restricted Areas.* The Panel questions the division of the 5 rems allowed annually under §20.101(*a*) into 1¼ rems per calendar quarter. The 1¼-rem quarterly limit implies an unwarranted degree of precision in dose measurement and is a questionable administrative limitation.

§20.102 *Determination of Accumulated Dose.* This section could be greatly simplified in the interest of creating a more understandable document. A reference to Form AEC-4 and to instructions accompanying it should replace many of the details and dose assumptions now included in §20.102.

§20.103 *Exposure of Individuals to Concentrations of Radioactive Material in Restricted Areas.* The Panel believes that this section could be simplified in terms of performance standards. The Panel supports AEC's proposal to allow credit for the use of protective clothing and equipment without the need of a special license approval. Again, advice and operational standards related to the proper use of such clothing and equipment could be included in a Manual of Good Practice.

In accordance with the Panel's suggestion that dose limits be established for occupational exposure rather than for individuals in restricted areas, it would be appropriate to add to §20.103 a limitation on nonoccupational exposures. Presumably the limit would be 0.5 rem/year in keeping with dose limits for members of the public.

The allowable limits of Part 20 for airborne concentrations are based on NCRP and FRC recommen-

dations. Although §20.201(*b*) requires licensees to keep records of air concentration, there is no requirement that estimations of dose from internal radiation be considered in an individual's exposure history. This was not an oversight. In the Statement of Considerations for the major revision of Part 20 effective Jan. 1, 1961, AEC noted that calculating and interpreting combined internal and external doses would not be a realistic requirement because of the lack of knowledge in this area. The statement went on to say that excessive organ doses from combined exposure would be rare and, in any event, an individual would not exceed twice the dose recommended by the FRC.

The Panel suggests that AEC review again the feasibility of estimating combined doses. At the very least, a Manual of Good Practice should address itself to this problem with such information as may be available for assisting licensees to estimate internal as well as external doses. The manual would then contain strong recommendations that significant internal doses be recorded and considered in the individual's exposure records wherever practicable.

§20.104 *Exposure of Minors.* The Panel notes that §20.104 does not reflect the NCRP recommendations for exposure of minors during educational activities (NCRP Report No. 32, July 1966).

§20.105 *Permissible Levels of Radiation in Unrestricted Areas.*

§20.106 *Concentrations in Effluents to Unrestricted Areas.* These sections would have to be revised in accordance with the Panel's recommendation that restricted and unrestricted areas be deleted from the regulations. In addition, those portions of §20.106 relating to exemptions should be limited to a statement of the criteria which the Commission will apply in considering requests for exemption. Details of the information to be provided in support of requests for exemption should be contained in guides and instructions relating to application for licenses and exemptions.

§20.201 *Surveys.* Much guidance in this area might be afforded to licensees in Manuals of Good Practice.

§20.202 *Personnel Monitoring.* Here again Manuals of Good Practice could provide guidance in such things as selecting the proper form of personnel monitoring equipment, interpreting the results, and using equipment to optimum advantage. The manuals might also provide guidance in the use of bioassays and whole-body counting, which can be considered forms of personnel monitoring. In this regard §20.108 dealing with bioassays might be combined with §20.202.

§20.203 *Caution Signs, Labels, and Signals.*

§20.204 *Exceptions from Posting Requirements.* The Panel understands that the AEC staff is presently preparing revisions of these sections which would substitute performance standards for the present unnecessarily rigid requirements on posting and labeling. The Panel encourages the early formulation and adoption of such revisions. This is one of the principal areas where performance standards and Manuals of Good Practice could profitably be substituted for detailed regulatory requirements.

§20.302 *Method of Obtaining Approval of Proposed Disposal Procedures.* This section should be confined to criteria that will govern requests for exemptions from waste-disposal restrictions. Details as to information to be supplied in support of exemption requests should be confined to separate guides and instructions to applicants for licenses and exemptions.

§20.305 *Treatment or Disposal by Incineration.* The prohibition on incineration should be replaced by provisions allowing incineration subject to the modified limitations of §20.106 on airborne effluents. A Manual of Good Practice could provide information on the combustion behavior of radioactive compounds, systems of record keeping, and procedures for disposal of ashes.

§20.401 *Records of Surveys, Radiation Monitoring, and Disposal.* The Panel devoted considerable attention to the matter of record keeping. Currently personnel exposure records must be retained for a period sufficient to demonstrate compliance. Inasmuch as it appears that such records may possibly have additional statistical value, and since further retention does not place an undue burden on licensees, the Panel recommends that personnel exposure records be retained for an indefinite period subject to periodic review of the value of their retention. In reaching this conclusion the Panel gave no consideration to the possible value of such records in workmen's compensation proceedings since this question is under review by another AEC advisory committee.

As to other records, a requirement for retention beyond the need to demonstrate compliance does not seem indicated (with the possible exception of airborne-concentration records, which might be significant in determining dose received from internal radiation). The Panel recommends that a reasonable requirement for retention be specified in the regulation.

§20.403 *Notification of Incidents.* The Panel has reviewed preliminary proposals by the AEC staff for revision of the notification requirements and approves of the directions the proposals take. In particular, the Panel agrees that there appears to be no health and safety reason for requiring licensees to report incidents that result in time loss or property damage if there has been no overexposure or excessive release of radioactive materials [§§20.403(*a*)(3) and (4) and 20.403(*b*)(3) and (4)].

(FEM)

Section

VII

Isotopes and Radiation Technology

Isotopes Around the World

Industrial Radioisotope Applications in the Philippines

By Bernard A. Fries*

In an effort to develop further interest in the use of radiotracers in Philippine industry, the U. S. Agency for International Development, through its contractor, the University of Virginia, and the Philippine Atomic Energy Commission jointly sponsored a 5-week demonstration program in early 1967 on problems of industrial interest in the Philippines. The author was invited to participate in this program.

In the Philippine Republic, with a small but growing industrial base, there exists a strong nucleus promoting isotope technology, with increasing emphasis on industrial applications. The technical and informational leadership comes from the Philippine Atomic Energy Commission (PAEC). Since market demand is greater than actual production for most Philippine industries, improvements in technology that lead to increased productivity can be very valuable. A receptive attitude prevails in this nation for utilizing radioisotopes, and there is an increasing recognition on the part of its industrial managers that radioisotopes can be beneficial to its economy. Commercial use of radioactive sources for radiography has already been developed, but prior to 1967 there had been no examples of radiotracer uses by industry.

To make effective use of the short time available, the Research and Development Division of the PAEC contacted representative Philippine industries in advance to try to identify problems of interest. A well-organized program was prepared from their suggestions, making it possible to work on some problems immediately and to lay plans for those of longer range.

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Applications

Most of the problems considered were similar to those that crop up in industry throughout the world. Many were concerned with water tracing and flow measurements in the process industries.[1–6] These could be handled immediately and could lead to practical demonstrations — an effective way to acquaint industrial managers with radioisotope techniques. To facilitate this effort, portable counting equipment and isotopes suitable for water tracing, but not immediately available in the Philippines, were shipped in advance from the author's laboratory. These included a battery-operated scaler, a high-sensitivity bundle of gamma-ray Geiger tubes in a waterproof container, ^{60}Co as the cyanide complex, and tritiated water.

Problems to which satisfactory solutions were found were water flow in a gold mine, intake and residence time of cooling water in the holdup pond of a soda ash plant, and petroleum refinery flow and leak rates. Several applications in glass and cement factories and study of leakage of water from the Baguio City reservoir were discussed for future application of radioisotopes.

GOLD-MINE WATER FLOW

Preliminary discussions between the PAEC and the mine operators had concerned the seepage of drainage water from higher to lower levels. However, when the mine was visited, more interest was shown in water-flow measurements. Therefore detailed plans for making such measurements were drawn up the first day, and simple auxiliary equipment was fabricated in the mine shops for introducing the tracer into the flows. On the second day, four large flow rates were measured, two of these deep within the mine. The technique used was the total-count

method[7] with ^{60}Co tracer. A 55-gal oil drum was used for the fixed counting volume for the Geiger-tube bundle; it was calibrated on the spot, using an aliquot of the starting tracer solution. The water being delivered by two pumps from the 2600-ft level to the 2000-ft level, the entire drainage at the mine portal, and the flow in an 8-in. line delivering water from the mine to the mill were measured. These flows ranged from 300 to 5000 gal/min.

For the deep mine pumps, the tracer solution was introduced into the pump through a funnel attached to the suction side. Where the pumps discharged at the 2000-ft level, the hydrostatic head was so low that water had to be pumped out of the line into the counting drum with the aid of an auxiliary pump. On the line to the mill, the tracer was forced into the pipe using mill air pressure. At the mine portal the tracer solution was poured directly into the drainage ditch. Farther downstream an auxiliary pump was used to deliver water from the ditch to the counting drum.

The mine engineers and operators ably assisted in all the tests.

SODA ASH PLANT COOLING-WATER DISPOSAL

In a soda ash plant, cooling water containing traces of free chlorine is discharged into a holding pond to permit addition of chemicals, as needed, to decrease the chlorine content before final disposal. Two ^{60}Co tracer measurements were made: the flow rate into the pond and the residence-time distribution in the pond. The flow rate was measured by the total-count method,[7] with the Geiger-tube bundle completely immersed in a canal leading to the pond. The residence time was measured by adding the tracer all at once to the inlet of the pond and counting the discharged tracer with the counter bundle at the outlet canal. The discharge observed was characteristic of a large amount of short circuiting and indicated that there was probably insufficient treatment to reduce the chlorine content. Addition of two flow baffles was recommended. As a bonus, the volume of the pond was computed from the inlet flow rate and the average residence time.

PETROLEUM REFINERY FLOW AND LEAK RATES

A discussion of process control problems with the operating staffs of two large refineries suggested that their problems are similar to many that have already been successfully solved by radiotracer techniques in U. S. refineries. These included determination of solid-catalyst circulation rates; determination of leaks in process heat exchangers and measurement of leak rates; measurement of gas, steam, and liquid flow rates; and level gaging with radioactive sources.

One refinery is well on its own way toward applying radioactive methods, particularly in level gaging and catalyst-circulation-rate measurements. This refinery has also pioneered in the use of radioisotopes in industrial radiography in the Philippines. Their skillful engineers have made use of these sources in solving process operating problems outside the scope of conventional radiography.

Similar problems were discussed at another refinery. The operators expressed interest in learning the flow rate of water from their cooling tower, which supplies all the cooling water to the refinery. The previously mentioned counting equipment and ^{60}Co tracer were used. A 55-gal oil drum was connected with some simple piping to the main flow line, and the tracer was poured into an open canal at the base of the tower leading to the pumps. A flow rate of 35 million gal/day (±5%) was found. The entire operation was completed in less than an hour.

OTHER APPLICATIONS

Some very interesting potential applications were discussed at a large glass factory. These included the well-known use of embedded radioactive sources to determine remaining furnace wall thickness; the determination of mixing of batches and possible subsequent segregation; the residence time of glass in the melting tank; and some unusual problems in the lubrication of the glass-forming machines.

At a large cement plant, measurement of the residence time of clinkers in the kiln and the control of the specific gravity of cement slurry by radioactive methods were discussed.

The leakage of water from the Baguio City reservoir is a difficult study. The loss may occur beneath the masonry dam or, more likely, through a porous, probably cavernous, limestone formation in the floor of the dam. Radiotracer techniques have been employed in similar studies elsewhere and should be applicable to this problem for determining the water outlets. Tritiated water tracer or several gamma-ray emitters as used elsewhere would be appropriate. Unfortunately, at the time of the visit, the reservoir was completely dry.

Participation by the Philippine AEC

The Research and Development Division of the PAEC, besides conducting the initial industrial surveys, made offices and facilities available for this work. Both senior and junior staff members actively participated in the experimental phase. The PAEC, through its Research Division and Training Division at PAEC headquarters in Manila, also conducts training courses in radiography, radiological safety, and industrial radioisotope technology.

Another active group is the Radioisotope Society of the Philippines. Its 700 members comprise many graduates of the training courses as well as others

interested in chemical, agricultural, and medical research applications of radioisotopes.

(PSB) and (MG)

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Long-Range Program for the Application of Radioisotopes and Radiation in Japan*

By Toshinosuke Muto†

The Japan Atomic Energy Commission (JAEC) worked out the Long-Range Program for the Development of Atomic Energy in February 1961 and, under this program, has promoted development of the peaceful uses of atomic energy in science and technology. Because of recent extensive developments — implementation of the construction program of both a nuclear fuel-processing plant and of Japan's first nuclear ship, formulation of necessary policies on the development of power reactors, and promotion of the applications of radiation both in Japan and abroad — the JAEC revised its long-range program in April 1967. This article summarizes briefly the part of the program concerned with the application of radioisotopes and radiation.

Radioisotopes are used as both tracers and a source of radiation, and applications of radioisotopes and radiation are spread over many fields: basic sciences, e.g., physiology, biochemistry, solid state physics, space physics, geophysics, and archeology; medicine, for diagnosis and therapy; agriculture and biology, for stock improvement, crop protection, and improvement and conservation of the products of forests, stock farms, and fisheries; and industry, for process control, quality improvement, and new product development.

Further development in all these fields will require a ready supply of radioisotopes, the enlargement of facilities, the evolution of use techniques, and the development of suitable radiation standards. Also of significance will be the spread of use techniques into new fields, the exchange of information, the international exchange of research workers, and the training of young scientists.

Medicine

Medical applications of radiation have developed greatly as a result of the introduction of both new types of nuclides and new kinds of measuring instruments. Tracers, internal organ scanning, and irradiation by radioisotope radiation are extensively used in diagnosis and therapy. We believe that radioisotopes will make important contributions to human welfare in the future.

Radioisotope tracers are used both to determine the origins of disease by clarifying the physiology of the pathological state and to set up the method for medical treatment. Scanning of internal organs is now becoming an indispensable technique in the diagnosis and treatment of malignant tumors in lung, brain, and other internal organ tissue. Irradiation is generally regarded as a highly effective and important technique for cancer control.

Research on medical applications will be promoted at universities, the National Institute for Radiological Sciences, and other government medical treatment facilities. Universities are responsible for research in all fields, including basic research, and for the training of young workers. The National Institute for Radiological Sciences was originally established for both basic and clinical technology research and is responsible for the development of new labeled compounds, of new short-lived nuclides that emit low-

*Presented at the 8th Japan Conference on Radioisotopes, Tokyo, November 1967.

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energy gamma rays, and of methods for diagnosis and therapy using an electronic computer. Government medical treatment facilities will do basic and clinical research on the diagnosis of disease and treatment of malignant tumors with radioisotopes.

Recently, radiation sterilization of hypodermic needles has become of interest to doctors, nurses, and medical research workers. Research and development for the practical use of this technology will probably be done at the National Institute for Radiological Sciences and at government medical treatment facilities in local areas.

Biology and Agriculture

Work on the biological and agricultural applications of radioisotopes and radiation has been promoted mainly at universities and government experimental facilities. Some interesting results have already been obtained, and research is continuing. Thus far, applications of radiation in biology and agriculture have been in research on animal and plant nutrition, fertilizers, agricultural chemicals, and plant mutations. We plan to emphasize large-scale experiments on radiation-induced mutations and study of fertilizers and agricultural chemicals that increase agricultural production and resources.

In the field of radiation-induced mutations, new and excellent rice and soybean plants have been developed, and superior plants have been selected for promulgation. This research is to be intensified, and internal irradiation of plants by absorbed radioisotopes as well as external irradiation with neutrons and charged particles will be investigated. The basic research on radiation biology and genetics will be conducted chiefly at universities and government genetics research institutes, and methods of inducing mutations and of selecting and breeding of mutants will be conducted at government experimental facilities and at the National Institute's Irradiation Field. Large-scale experiments on labeled fertilizers will be carried out in a producing field together with activation analysis studies.

Industry

The applications of radiation have been extended to underground, water, ocean, and space sciences, and significant progress is being made. Especially active is the research on the use of radioactive fission products, in which encouraging results have been obtained. Policies for the dissemination of applications technology into industry will be considered.

The industrial fields in which development is expected to continue are on-stream analysis and process control, computer analysis of radiation-measurement data, analytical chemistry, solid state physics, and uses of radioisotopes in hydrology, civil engineering, underground resource development, transportation technology, and pollution control. Study of isotope generators of electricity will be started, and applications of radioisotope radiation to space and marine sciences will be promoted.

An Applications and Development Section has been set up in the Japan Atomic Energy Research Institute (JAERI) at the Radioisotope Center. It is expected to function as a coordinator of work on uses of radioisotopes and radiation.

Radiation Chemistry and Food Irradiation

Radiation chemistry, i.e., the characteristic chemical reactions induced by radiation, has developed with respect to both basic research and applied technology. The importance of basic research in radiation chemistry has drawn particular attention, i.e., the elucidation of chemical reactions, discovery of new reactions, and instrument engineering. JAERI's Takasaki Laboratory will be responsible for industrial-scale tests on promising processes such as the graft polymerization of fibers and gamma-irradiation polymerization of ethylene. The Osaka Laboratory will be responsible for related basic research.

The use of radiation for preserving food during transportation and storage will significantly alleviate food shortages, and the broad program will include selection of foods suitable for irradiation, after which active steps will be taken for industrialization of food-irradiation processes. On September 21 the JAEC approved a program on food irradiation, establishing a comprehensive research plan.

In 1967 our first 3-year plan of research on prevention of germination in potatoes and onions was initiated. A 5-year program for studying prevention of insect damage to rice is also being started. Prospects for the industrialization of the results in this field will be clarified by 1974.

A continuing research program will be started on basic technology of packaging and development of irradiation equipment. An Operations and Working Committee on Food Irradiation will be set up in the JAEC, and a large-capacity irradiation facility will be constructed, hopefully to be in operation by 1970. The research facilities of JAERI and of the Institute of Physical and Chemical Research are responsible for promoting these programs in cooperation with industry.

Production and Distribution of Radioisotopes

It is difficult to determine long-range demands for production of radionuclides. However, we can expect the total demand to at least double in the next 10 years. Most radioisotopes used today in Japan are imported, but JAERI will attempt routine production

in the very near future. In the next 5 years, production of processed radioisotopes will be actively developed, and in the subsequent 5 years, radioisotopes will be produced for radiation sources, and desired radioisotopes will be separated from fission products.

Industry is expected to produce most of the radioactive drugs and labeled compounds. The Japan Radioisotope Association will cooperate in the distribution of domestically produced radioisotopes.

(MG)

Routine Industrial Applications of Radioisotopes in the World*

By C. K. Beswick†

Although much has been said and written about the technical and economic advantages of applying radioisotopes to the solution of industrial problems, industrial applications of radioisotopes have lagged behind those in agriculture and medicine for many years. The reasons for this are not clear, but there is evidence that the situation has now changed. In some countries radioisotope techniques are completely accepted and judged solely on their ability to provide a certain measurement or solve a particular problem in competition with other methods. In other countries the radioisotope specialist still has to convince industry that radioisotopes can improve quality and efficiency, reduce plant shutdown time, and perhaps effect a considerable economic benefit without contaminating products or damaging the health of workers. This paper summarizes the extent to which radioisotope techniques have been accepted and are in current use. The figures quoted are not intended to be complete but only to indicate the growth of industrial applications throughout the world.

Instruments

Table 1 shows the most recently available figures on the number of instruments of different types installed in the Union of Soviet Socialist Republics (USSR), United Kingdom, France, and Czechoslovakia. Subsequent increases in both the United Kingdom and France have been considerable, and increases in other countries, not listed here, are believed to be even more dramatic.

Table 1 RADIOISOTOPE GAGES INSTALLED IN USSR, UNITED KINGDOM, FRANCE, AND CZECHOSLOVAKIA

Application	No. of gages			
	USSR (1961–1965)	United Kingdom (1961)	France (1961)	Czechoslovakia (1966)
Thickness gages	1,054	718	374	105
Density gages	1,314	982	48	30
Relays, including level gages	18,000	300	858	115
Moisture gages	64	6	140	15
Component determination and other gages	-	24	45	25
Total	20,432	2,030	1,465	290
1966 estimate	-	14,000	3,000	-

THICKNESS GAGES

In 1961 an IAEA survey‡ showed that, excluding the United States and the USSR, some 3500 thickness gages were installed in 20 industrialized countries, 40% of these in the paper industry. This figure has increased considerably, and an estimate of present usage would be close to 20 thousand. One European manufacturer has sold 4500 thickness gages, another 1500, and two smaller companies 600 and 850, the latter being installed only in the paper industry.

In the United Kingdom, only 718 thickness gages were installed in 1961 out of a total of 2030 instruments, but this total is now believed to have doubled, the increase coming mainly from thickness gages. In France about 3000 radioisotope instruments are in use in industry at present, compared with 1465 in 1961, but the increase in thickness-gage usage is thought to be very small.

DENSITY GAGES

The largest single radioisotope density gaging application is still that used to check the uniformity of tobacco in cigarette manufacture. These gages are now supplied as standard measuring equipment on some cigarette-making machines and are used to

*Presented at the 8th Japan Conference on Radioisotopes, November 1967, and based principally on a study tour in Czechoslovakia, France, the Soviet Union, and the United Kingdom in 1966.

†International Atomic Energy Agency (IAEA), Vienna.

‡*Industrial Radioisotope Economics*, Findings of Study Group Meeting, Vienna, 1964, IAEA, Vienna, 1965; reviewed in *Isotopes and Radiation Technology*, 3(2): 152-166 (Winter 1965–1966).

automatically control tobacco packing density. Although this relatively simple and inexpensive type of gage is known to give significant economic benefits and improved quality control, its use in some countries is still ignored. In spite of this, several thousand beta gages of this type are in use, e.g., about 3 thousand in the United States.

Gamma gages for measuring and controlling the density of liquids and slurries are limited mainly to the oil, chemical, food, and mineral processing industries. Some 5 thousand such instruments are in use in the United States. These instruments are also used in conjunction with flowmeters to measure mass-transfer rates. Belt weighing of solids, by means of strip sources and long detectors, is an increasing requirement, but so far only about 20 have been installed in the United States.

RELAYS AND LEVEL GAGES

The largest class of radioisotope instruments used industrially is undoubtedly the beta or gamma relay. Whether used as switches in electrical instruments such as voltmeters or temperature regulators or as level indicators in tanks and hoppers, they are still basically simple electronic units that have proved their reliability. In the USSR, where 18 thousand of these instruments are installed, radioisotope transducers are preferred to photocells, electromagnetic or capacitance pickups, or microswitches since they require less frequent servicing and their cost is comparable to the classical devices.

One instrument manufacturer in the United Kingdom has sold more than 6 thousand level indicators of the on–off, continuous, and package-monitor type, and a French company has produced over 1500. The obvious advantage of this no-contact, externally mounted system has led to the installation and complete acceptance of this type of radioisotope instrument in many countries. About 50% of the French increase in use of radioisotope gages mentioned above is thought to be due to level gages. Although systems using radioisotopes to control the level of blast-furnace charge show considerable technical and economic advantages over the older techniques, there are very few installations of this kind.

MOISTURE GAGES

Combined neutron moisture and gamma density gages are used extensively in civil engineering in a few countries, although in others their advantages and flexibility are questioned. In the United States, some 300 of these instruments, mainly of the surface type, are used for highway construction. Subsurface instruments are used mainly for agricultural and hydrological investigations, but their use in construction work is expected to increase when refinements, e.g., automatic density correction, are more widely adopted.

Installations exist for measuring and controlling the moisture content of foundry sand, sinter, and cement and are becoming more numerous now that their capability has been proved.

ANALYSIS INSTRUMENTS

The number of beta-, X-, and gamma-backscatter and of radioisotope X-ray-fluorescence gages in routine use is still relatively small. The main applications are still for coal-ash and coating-thickness measurements and mineral analysis. The commercial availability of portable radioisotope X-ray-fluorescence analyzers has led to a new concept in mineral assaying. Although less than 100 of these instruments are in routine use, their adaptation for mineral analysis in the field has reduced the demand for chemical analysis—a factor of considerable importance in developing countries. On-line applications in mineral processing are even less numerous, but successful installations exist and their number will undoubtedly increase rapidly in the near future.

Preferential-absorption techniques are largely limited to the determination of sulfur, chlorine, and lead in the petroleum- and chemical-refining industries where these measurements are used both in the laboratory and on-line.

Tracers

Table 2 shows the geographical distribution of radioactive tracer usage in industry. The information was compiled from details received from IAEA member states in 1966 in response to a request for statistics on routine radioactive tracer applications.

WEAR AND LUBRICATION

Almost all the major oil companies use radioactive engine parts to test the efficiency of lubricating oils. Statistics are difficult to obtain, but one company in the United Kingdom has irradiated 224 piston rings during the last 3 years, has three engines running continuously for these studies, and tests about 50 different lubricating oils each week. If this is indicative of the extent of this type of application, it must be one of the largest routine tracer uses in industry.

FLOW RATE

Flow-rate measurements are reported by most countries, mainly by the peak-to-peak method. Refinements in techniques such as injection and counting have led to the complete acceptance of radioisotope methods, particularly for turbine rating checks. These same refinements have in some countries enabled the use of radioisotopes to become standard practice for residence-time distribution studies in acceptance tests. Advanced data-handling methods make full use of the results of these experiments.

Table 2 GEOGRAPHICAL DISTRIBUTION OF ROUTINE RADIOACTIVE TRACER USAGE

Country	No. of organizations	No. of people employed	Routine uses
Austria	3	24	Leak detection, air movement, flow rate, mixing efficiency, water movement, oil exploration, activable tracers
Australia	4	25	Leak detection, flow rate, pollution studies, material transport, mixing, residence time, ventilation studies, volume measurement
Canada	10	-	Oil-well investigation, leak detection, mineral dressing, solvent extraction
Czechoslovakia	250	150	Material transport, flow rate, leak detection, chemical kinetics, leak testing of transistors, tire wear, engine wear, residence time, oil-well cementation
Hungary	4	-	Solidification and circulation, furnace-lining wear, contamination source, purity control, flow rate, material transport, flow pattern, mixing, leak detection
Israel	4	20	Leak detection, material transport, flow rate, residence time, mixing, pollution studies, ventilation studies
Italy	68	-	Engine wear, chemical processing, metallurgy, geophysics, mixing, residence time, oil-consumption measurement, hydrological research
Japan	Numerous	-	Engine wear, refractory wear, aluminum volume, leak testing, residual pig iron, Hg in NaOH
Netherlands	15	57	Leak detection, retention time, mixing studies, water migration, silt and sand movement, flow rate, flow pattern
Norway	2	10	Flow rate, flow pattern, dilution analysis, pollution studies
Philippines	2	6	Leak detection, underground water, catalyst flow
Poland	7	120	Mining, metallurgy, chemical technology, petroleum, geophysics, well cementation, rock porosity, material transport, process kinetics, leak detection, wear, steel inclusions, charge movements
Spain	3	20	Leak gage and flow rates, Hg in NaOH, engine wear
Sweden	1	9	Furnace-lining wear, leak detection, paper-machine testing, material transport, mixing studies, volume determination, effluent discharge, river flow velocity, dispersion in receivers, furnace wear, labeling for identification, nonmetallic inclusions, slag weight
United Kingdom	142	-	Material transport, mixing studies, volume determination, leak detection, effluent discharge, friction, wear, labeling

LEAK DETECTION

Leak detection by means of radioisotopes is, in principle, one of the simplest tracer applications. Although this use is reported by every country, perhaps only three organizations have a sufficient number of requests to employ staff exclusively for this purpose. Their activities are confined mainly to investigations on buried pipes and heating systems.

VENTILATION

A simple and rapid technique for measuring ventilation rates is widely used by several organizations. The method, which is particularly useful for checking air-conditioning requirements, eliminates the need for sampling and gives accurate measurements of air renewal rates.

POLLUTANT DISPERSION

The dispersion of pollutants, such as sewage and industrial waste, into the sea has been the subject of intensive studies by means of radioactive tracers, especially in Denmark and Sweden. In these countries automatic recording systems and computer programs have been developed to make this one of the most successful tracer techniques in use at present. Studies on airborne pollution, using both radioactive and activable tracers, are becoming more widespread, and methods developed in Japan have proved the effectiveness of tracer techniques for the purpose.

IAEA Activities

The range of activities covered by the Industrial Applications Section of the IAEA can be divided into four main groups:

1. Analysis, testing, and control: e.g., radiography, gaging, X-ray-fluorescence analysis, activation analysis, nuclear geophysics, and static elimination

2. Industrial radiation processing: engineering, physical, and chemical processes

3. Tracers: plant and field studies and environmental control in rivers, seas, and air

4. Energy sources: light and power sources and pacemakers

MEETINGS

The IAEA has been actively engaged in promoting industrial applications of radioisotopes since 1959 when the first symposium in this field was organized. Since then eight other meetings and eight panels and study groups have attempted, on an international basis, to coordinate recent developments and activities of interest to all member states.

Symposiums in 1965 and 1966 covering all industrial applications of radioisotope instruments and radioactive tracers were meant to be the last dealing with the whole field. Radioisotope techniques have now become so widely adopted that detailed coverage cannot be given to specific subjects in general meetings, and in 1968 the first specialized symposium will be held on Nuclear Techniques in the Exploration and Development of Mineral Resources. Future meetings will cover the uses of radiation in industrial processing and nuclear techniques in civil engineering and pollution.

A recent panel dealing with applications of radioisotopes in the pulp and paper industry was the first attempt to bring together radioisotope specialists, instrument manufacturers, and users to discuss common problems. The meeting was so successful that strong recommendations were made to distribute the report of the meeting widely in both developed and developing countries and to cover other manufacturing industries in the same way. There is still a considerable gap to be filled in information distribution, and potential users in even the most advanced countries are largely uninformed about this modern technology.

A Study Group on Impregnated Fibrous Materials will concentrate on the work being done in this area in Asia and the Far East. Although wood–polymer systems have long been studied, other materials such as bagasse, bamboo, jute, lignum, and cotton show promise, particularly in this region, and the Study Group will attempt to define areas suitable for potential commercial exploitation which might benefit the whole region.

The use of neutron moisture gages has continued to grow in recent years, but there is evidence that some of these instruments are not being used to their full advantage. The terminology associated with them is misused and not universal. To try to correct this, the Agency has convened several consultants' meetings, culminating in a list of terms and definitions which, it is hoped, will form the basis for international agreement. A Guide Book on the use of neutron moisture gages will be published in 1968.

As a result of a Study Group on Radioisotope Power Generators, joint ENEA–IAEA recommendations on the safe installation and use of these devices will be promulgated. The international aspects of the development and application of radioisotope power generators are being closely studied by the Agency.

TRAINING

In 1966 the Agency, in cooperation with the Government of Mexico, organized a regional training course on industrial applications of radioisotopes for Latin American countries. The course was a first attempt to give in-plant training on a large scale. Detailed instruction was given on industrial instruments such as thickness, density, and level gages, and visits to factory installations were made to acquaint participants with the conditions under which these instruments must work. Radioactive tracer experiments were carried out in factories to measure flow rates, retention times, ventilation rates, and losses due to leakage. This attempt to upgrade the more usual laboratory-scale type of training course to a practical and applied level was most successful, and it is hoped to repeat it in other regions.

A Study Tour* lasting 2 months was also organized in 1966. Fifteen senior scientists from 15 developing countries were conducted through the Soviet Union, United Kingdom, France, and Czechoslovakia to see ways in which radioisotopes and radiation are used on an industrial scale. This first such tour organized by the Agency gave the participants the opportunity of learning, at first hand, methods and techniques that could be applied immediately in their own countries to improve and optimize manufacturing processes.

The growing interest in applying radioisotope techniques to industry is shown by the increased number of requests received from member states for assistance in this field. Between 1959 and 1966, ten technical assistance experts gave advice to eight member states. In 1967 and 1968 there are 16 requests for assistance in radiography, thickness gaging, tracer applications, and elemental analysis.

FUTURE TRENDS

Although interest in such things as radioisotope instruments for process control and radioactive tracers for process efficiency studies is likely to be maintained for many years, some specific areas can be picked out as developing more rapidly than others.

Environmental pollution is one of the most serious problems facing the world today. Radioisotope in-

*Industrial Applications of Radioisotopes and Radiation in Czechoslovakia, France, the Soviet Union, and the United Kingdom, Report of Sept. 1–Oct. 27, 1966, Study Tour, IAEA, Vienna, 1967.

struments for analysis and radioactive and activable tracer techniques for dispersion studies are, in some countries, contributing significantly to the solution of this problem. The Agency is becoming increasingly involved in this field, which is likely to develop into a major activity in the future.

In the exploration and exploitation of oil, gas, metals, and other minerals, nuclear geophysics is playing an increasing role. The effectiveness of these techniques can be judged from the fact that, in the USSR, their use has directly resulted in a reduction by a factor of 5 in the number of exploratory wells drilled. The use of natural gamma logging, neutron logging, gamma–gamma logging, and neutron and photon activation is already extensive and will increase as the use of sophisticated exploration techniques is expanded. Preferential-absorption, backscatter, and X-ray-fluorescence methods, already developed and used on a limited scale, will undoubtedly be used more for analysis and enable rapid and direct measurements to be made in mining and mineral processing plants.

In recent years there have been rapid developments in the use of radiation in industrial processing, and there are indications that many processes involving the use of radiation to initiate reactions are about to become commercial. These processes will represent technological and economic breakthroughs, and the Agency will probably play a more active part in ensuring that the benefits of this research are passed on to assist industrial development.

(MG)

Saclay Facility for Preparation of Radioisotope-Labeled Materials*

The work of the department charged with the responsibility of manufacturing labeled materials at the Centre d'Études Nucléaires at Saclay increased fivefold in the period 1960–1964. The amounts of radioactive materials used in 1964 (5 curies of ^{14}C and several tens of curies of tritium) taxed the building's safety provisions, and the need for a new building became critical. A building was constructed and in December 1965 was formally opened for use. The amounts of ^{14}C and tritium used in 1966 had increased to 9 and 1500 curies, respectively. The new facility, as it was being used in mid-1967, is described here.

Building

The building (Fig. 1) for preparing labeled materials has a total floor space of 1500 m^2. Radioactive syntheses are carried out on the ground floor in six identical laboratories, which open onto a central corridor. Each laboratory is designed for four operators and contains laboratory benches, hoods, and glove boxes and has an adjoining office. Laboratories for performing special physicochemical techniques are also on the ground floor. In the basement are a laboratory for making deuterated materials, an electronics shop, a cold room with compartments at −35 and −80°C for storage of labeled organic compounds, and a liquid-nitrogen storage room (−190°C).

VENTILATION

Since all radionuclides handled in the facility are weak beta emitters, special shielding construction and remote-controlled manipulators are not required. However, some of the products synthesized are powders or have high vapor pressures, and very good ventilation had to be provided. In each laboratory the hoods are connected to nine vents which exhaust air at a high flow rate and low pressure differential; the glove boxes are arranged around five vents, and air leaking in is exhausted at a low flow rate and a high pressure differential. Air entering the building is heated and humidified as necessary, and outgoing air is filtered to remove any solids present.

The entire active zone is at an average gage pressure of about −5 mm H_2O, with the air-flow path designed to go from the offices and corridors, where no radioactivity is handled, to the special-techniques laboratories and finally to the laboratories where radioactive materials are present. The air is renewed 14 times per hour in the laboratories and 8 times per hour in the other rooms; the total air flow through the building is 60 thousand m^3/hr.

SERVICES

Both nonradioactive and radioactive solid, liquid, and gaseous effluents are disposed of by the usual procedures. Contaminants in gaseous effluents are

*Based on C. Baret and L. Pichat, Labeled-Molecule Building and Its Equipment (in French), *Bull. Inform. Sci. Tech. (Paris)*, No. 118: 11-23 (September 1967). The editors of the French journal kindly supplied the photograph of the facility.

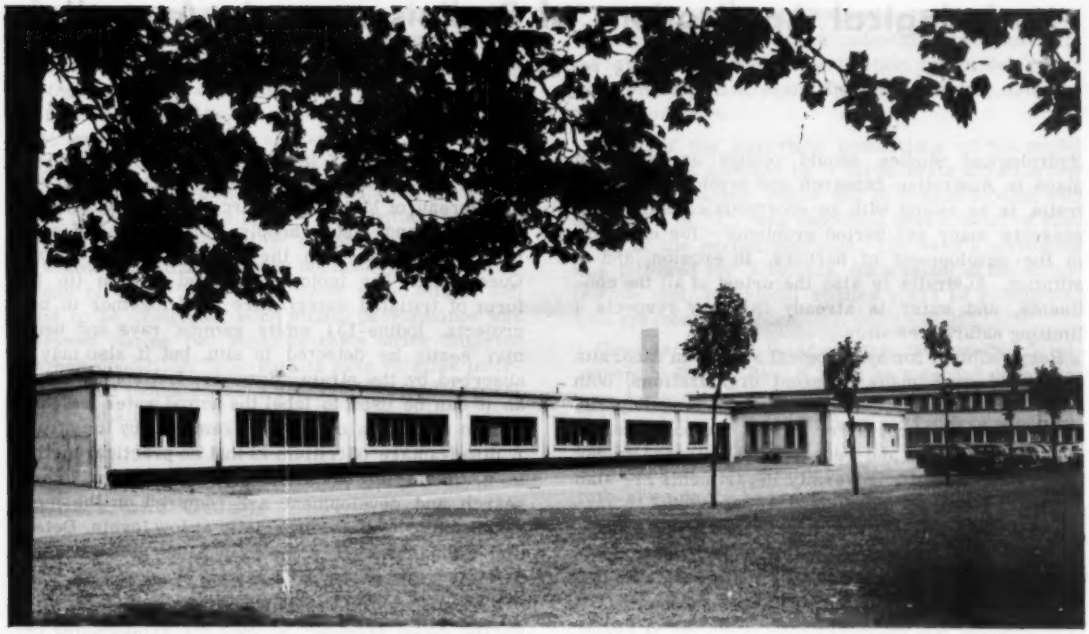

Fig. 1 Saclay facility for preparation of labeled materials.

converted to solids or liquids whenever feasible and handled with other similar waste products.

The building is supplied with standard water, electricity, gas, oxygen, nitrogen, and compressed-air lines. In addition, there is a helium supply for gas chromatography, as well as a supply of gas for the proportional counters used in radiochromatography. Both distilled and deionized water are available as needed.

Equipment

The hoods in the Saclay facility have both side and front windows that can be raised. The side windows provide access from the ordinary laboratory bench, and the front ones contain openings large enough for hand entry. These openings are closed by diaphragms or gloves. The hoods are supplied with standard lines, such as water and gas, with controls on the outside. Microchemical apparatus is provided for each hood. Underneath the workbench is located the extraction apparatus. Each laboratory has a storage rack and enclosed washing facility for glassware, with waste bins under the washing facility.

Special hoods for vacuum operations are supplied with standard lines, such as electrical and gas, but have only one cooling-water takeoff. Pans located under the working surfaces collect any spilled material and thus localize any contamination. The vacuum pumps are in compartments between the working surfaces and the floor.

The standard glove boxes are provided with external lighting to eliminate possibilities of explosion from this source. Ventilated glove boxes for column chromatography have provisions for automatic collection of effluents. The glove boxes for gas chromatography were specially designed of metal and have two sliding windows and three hinged windows. Everything that comes in contact with radioactive material is inside the box; electronic equipment is outside.

Contaminated glassware is decontaminated in special automatic washing and degreasing machines. Alkali-, acid-, and alcohol-resistant construction materials are used. (MG)

Hydrological Applications of Radioisotopes in Australia*

By W. R. Ellis and G. L. Milest

Hydrological studies should occupy an important place in Australian research and development. Australia is an island with an enormous coastline that presents many and varied problems—for example, in the development of harbors, in erosion, and in siltation. Australia is also the driest of all the continents, and water is already in many respects a limiting natural resource.

Responsibility for hydrological studies in Australia is spread over many different organizations, both State and Commonwealth, which are variously responsible for rivers, water supply, harbor development, agriculture, and research into diverse scientific fields. Several university departments are also engaged in aspects of hydrological research.

The Australian Atomic Energy Commission (AAEC), although primarily concerned with the study of nuclear power and associated raw materials, also has an active program directed to the production of radioisotopes and encouragement of the use of radioisotopes and radiation sources in Australia. To support this program, the Commission undertakes research into applications of radioisotopes and also assists where necessary in field and industrial projects.[3]

Part of the research effort of the Isotope Division is directed to the study of hydrological applications of radioisotopes, and the Division has already participated in a number of major field experiments. These are normally carried out in collaboration with some other sponsoring organization such as a state harbor or water supply and irrigation authority. The role of the AAEC in this area is to make available new and improved techniques involving radioisotopes and to encourage their application by organizations having direct responsibility for such applications. The use of radioisotopes in hydrology is complicated by the absence of any central research and development organization that would accumulate the necessary expertise and the specialized equipment required for the many different applications.

Groundwater-Flow Studies

The Isotope Division has carried out two groundwater tracing tests. The first was a small-scale project in 1961 at the site of the proposed Chowilla Dam near Renmark in South Australia. The second was a large-scale investigation,[4] in conjunction with the Bureau of Mineral Resources and the Queensland Irrigation and Water Supply Commission, of aquifer characteristics in the Durdekin Delta of North Queensland. The isotopes ^{131}I and tritium (in the form of tritiated water) were used together in both projects. Iodine-131 emits gamma rays and hence may easily be detected in situ, but it also may be absorbed by the strata. However, tritium is unique as it can be used to label the actual water molecule and so cannot be chemically removed by the strata. A disadvantage of tritium is that no practical method is available for its detection in situ. Further research and development are required on the measurement of tritium, especially at low levels. Detection techniques are complex because tritium emits only very-low-energy beta rays.

Fallout from the French hydrogen bomb tests in the Pacific could probably be used for groundwater research in Australia. This would depend on the atmospheric distribution of the tritium during its west-to-east passage from the southeast Pacific to Australia. A relatively large effort would be required to measure the very low levels of tritium in the large number of samples that would be required.

Dispersion and Mixing Studies

The Isotope Division has carried out a number of dispersion and mixing studies. Some examples of these are described below.

A manufacturer wished to discharge effluent from a proposed mill into the estuary of the Huon River, Tasmania. The State Health Department would agree only if it could be shown that no harmful accumulation of effluent in the river would result. A tracer test by the Isotope Division showed that the water at the proposed discharge point was rapidly cleared by the tidal cycles.

In Western Australia, dispersal of highly processed sewage effluent in the sea from an outfall 3000 ft from the shore and in 36 ft of water was determined using 60 curies of ^{198}Au. The ^{198}Au solution was continuously fed into the sewage effluent for 3 days and was traced until the corresponding sewage concentration was well below that considered to be a health hazard.

An investigation into the dispersal of suspended solid wastes was made for the Electricity Commission of New South Wales (N.S.W.) to determine the feasibility of sea disposal of fly ash from a large coal-fired power station under construction near

*Extracts from *At. Energy Aust.*, 10(1): 2-11 (1967). Some Australian radioisotope work has been reviewed earlier in *Isotopes and Radiation Technology*.[1,2]

†Isotope Division, Australian Atomic Energy Commission.

the N.S.W. coast. A slurry in which 50 curies of ^{198}Au was adsorbed on 100 lb of fly ash was fed into the ocean over a 5-hr period, and in the same period 250 tons of fly ash was dumped over it from a collier. By following the ^{198}Au, it was found that ocean currents soon carried the fly ash out to sea.

Radioactive ^{131}I, as iodide in solution, was used to trace the flow and mixing of power-station condenser water through a cooling pond.[5,6] By labeling the warm water at the power-station outlet, it was possible to follow quantitatively the horizontal and vertical spread of water for 8 days, after which mixing was found to be complete. Pond mixing performance was assessed during two separate tests under different weather conditions. The results gave valuable information and indicated some possibilities for improvement in mixing.

Sediment Movement in Rivers, Harbors, and Oceans

The Isotope Division of the AAEC has performed many sediment tracing tests.[7] One such test was undertaken to show the effect of the tidal cycle on silt movement in the Hunter River at Newcastle, N.S.W. Silt labeled with the short-lived radioisotope ^{64}Cu (half-life, 12.9 hr) was added to the bed of the river near the entrance to a steelworks channel. Several tests were made at different stages of the tidal cycle.

In other studies at Newcastle, the Public Works Department of N.S.W. has undertaken to investigate the siltation of Newcastle Harbor and to determine with the aid of a model the effect of deepening the harbor entrance.

Some of the important predictions of the model studies were checked by a large-scale siltation test outside the harbor where 200 lb of sand labeled with 50 curies of ^{51}Cr was deposited near a shoal of sand south of the harbor entrance. The sand's movement was followed for 3 months. As a result of the radioisotope test, the model studies could be interpreted with greater confidence.

Consideration is being given to the possible development of Botany Bay, N.S.W., as a second deepwater port for Sydney. Extensive dredging will be required, and knowledge of the pattern of sand movement is essential. In a recent test 100 lb of sand labeled with 30 curies of ^{51}Cr was deposited at each of six separate sites on the bed of Botany Bay, and the distribution of radioactivity about each site was determined over a 9-month period (Fig. 1). Little movement of sand was found, although a significant change in sand distribution occurred as a result of two large storms. Two developments in radioisotope technique resulted from these experiments: a new method[8] of labeling sand with ^{51}Cr and a method[9] for computer processing of results with direct printout of isoactivity curves of the distribution of radioactive sand on the sea bed.

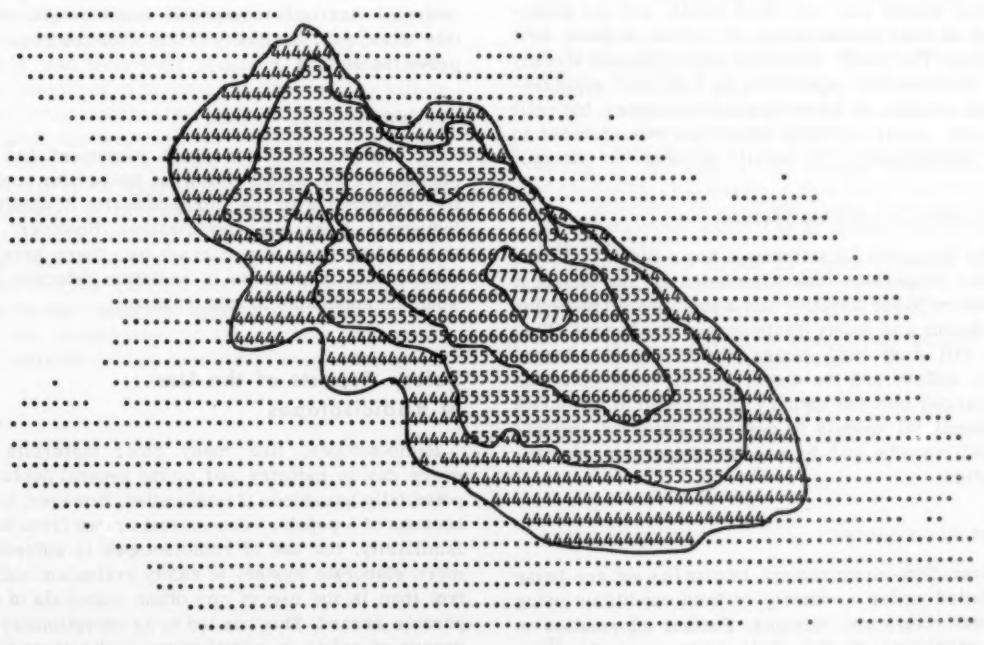

Fig. 1 Computer printout for a typical sand-movement test using ^{51}Cr at Botany Bay, New South Wales.

Research at Lucas Heights

The Commission's research program includes several projects concerned with possible hydrological applications of radioisotopes. Other research, e.g., into radiochemistry and radiation detection, provides the kind of support needed for such applications. Current research projects directly related to hydrology are discussed below.

GROUNDWATER STUDIES

As part of a study of aquifer characteristics, more information is being sought on the dispersion of liquids flowing through porous mediums. Laboratory-scale experiments are being carried out at the AAEC Research Establishment in collaboration with the Bureau of Mineral Resources, and these could lead to further field experiments.

Studies of methods of preventing adsorption of tracers on soil are necessary, with particular reference to soil from the areas to be examined.

Considerable effort is being devoted to the investigation of the use of tritium both as a tracer for underground water, etc., and as a measure of the age of underground stores of water. The program is initially focused on problems of tritium determination, including techniques for isotopic enrichment, radiation-counter development, and sample conversion and preparation. While the emphasis at present is on laboratory studies, it is planned that these studies should lead into field trials, and the possibility of field measurement of tritium is being considered. The AAEC Research Establishment already has considerable experience in low-level measurements relating to its environmental survey, but until recently relatively little effort had been devoted to the determination of small amounts of tritium.

DISPERSION AND MIXING STUDIES

The Research Establishment has a special interest in the dispersion characteristics of the adjacent Woronora River Estuary, and a joint project involving the Health and Safety Division and the Isotope Division will study tidal mixing, the influence of freshwater inflow, and the dispersion of waste solutions discharged into the estuary. It is hoped to formulate mathematical models to describe observed experimental results and to predict dispersion characteristics.

RIVER-FLOW GAGING

River-flow-measurement techniques are being evaluated under a variety of field conditions using several rivers and streams. Further information on the suitability of the main isotopes used—^{82}Br, ^{198}Au, and ^{3}H—is being obtained. The dispersion of the added radioactive liquid in a river under varying conditions is being studied to obtain more information on the siting of injection and sampling points. Inactive tracers are also being used, with the concentration of the tracer being determined subsequently by neutron activation analysis. The Commission has had considerable experience in the use of radioisotopes for river-flow measurements, and further study of the technique has been completed. A comprehensive review of the use of radioisotopes in river-flow measurement has been made.[10]

SEDIMENTATION STUDIES

As discussed previously, the Research Establishment has already made several improvements in the techniques of labeling sand and silt. Some further research will be required to extend the range of radioactive labels, but the main effort will be devoted to the improvement of techniques for the deposition of labeled sand in a range of experimental conditions, e.g., in deep water and rough seas. The possibility of determining the vertical distribution of labeled sediment without taking core samples is also being investigated. A wider application of computer techniques is also possible.

The Research Establishment is well equipped for studies of sediment movement, particularly in field-detection techniques and portable equipment. It may be possible to measure the movement of sand and silt to rivers and harbors (from land) using radioisotopes. Available equipment would be suitable for this work, but feasibility trials would be required to prove the method.

METEOROLOGICAL STUDIES

No further work on cloud movement has been planned by the AAEC following the earlier cooperative research with the Commonwealth Scientific and Industrial Research Organization. However, since this earlier work was carried out, there have been refinements in methods of radiation detection which would be applicable to this technique.

Safety Aspects of the Use of Radioisotopes

Radioisotopes, like many other materials used every day in industry and by the general public, are potentially hazardous if mishandled. However, largely because of a popular concern that arises from lack of familiarity, the use of radioisotopes is subject to a more elaborate system of safety evaluation and control than is the use of any other materials of comparable hazard. This has led to an exceptionally good record of safety in radioisotope applications both in Australia and elsewhere.

While the quantities of radioisotopes required for the applications described above vary greatly, two general characteristics of their use in hydrology are particularly favorable to safety aspects—the availability of substantial quantities of water for dilution and shielding and the possibility of selecting radioisotopes of short half-life and relatively low biological hazard.

Each external radioisotope project undertaken by the Commission is subject to a detailed safety assessment, which is considered not only by the Commission's own safety organization but also by the relevant State Health Department and by the Commonwealth Department of Health. These assessments take into account every conceivable contingency and are based on the most stringent safety rules. For example, in a typical stream-flow-gaging experiment, the radioisotope is almost immediately diluted to less than drinking-water tolerance—i.e., to a level that, according to internationally accepted standards, would be completely harmless for daily intake for a lifetime. When short-lived radioisotopes are used, the rapid decay of the radioisotope gives a further safety factor.

Conclusions

Most of the hydrological projects that have been carried out by the Isotope Division of the AAEC over the past 6 years have been collaborative, and many have formed parts of developments of substantial economic significance. Because of the magnitude of the effort involved and the substantial backup in equipment and technology required, it seems likely that for many years to come the Commission will be the only organization able to undertake large-scale hydrological applications of radioisotopes, even though every effort is being made to interest and train representatives of appropriate industrial consultant organizations. In this as in other fields, the Commission is undertaking research designed to extend the applications of radioisotopes in Australia. This research can be carried out successfully and can lead to further practical applications only if it receives the cooperation of the various authorities within Australia which have direct responsibility for hydrological matters. It is our experience that such cooperation can be expected.

Apart from the development that may result from further research, it is already possible for radioisotopes to be used in the solution of a wide variety of hydrological problems. It is hoped that the interested authorities will ensure that full advantage is taken of the availability of these techniques within Australia. (REG)

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Section

VIII

Isotopes and Radiation Technology

Miscellaneous

Conferences

Packaging of Radioactive Materials Meeting at Gatlinburg

The Second International Symposium on the Packaging and Transportation of Radioactive Materials is set for October 14–18 in Gatlinburg, Tenn. The meeting is sponsored by Union Carbide's Nuclear Division and by the AEC. Topics to be discussed include new transport regulations and their implications, operating experience in national and international shipments, and shipping containers for unirradiated fissile material, isotopes, and spent fuel. The program, chaired by K. W. Haff of Oak Ridge National Laboratory, may also cover specifications for shipping containers, research and development in container design and testing, insurance problems, carrier problems, and anticipated problems for the period 1970 to 2000.

IAEA Sponsors Meeting on Insect Control

Scientists from more than 30 countries met in Vienna in early December 1967 to attend a symposium sponsored by the International Atomic Energy Agency (IAEA) and the Food and Agriculture Organization (FAO) of the United Nations on the use of isotopes and radiation in entomology. Proceedings will be published by IAEA.

In the opening address, Dr. Seligman (IAEA) pointed out that there are 2.5 million kinds of insects in the world; many of them are harmful to man. Nuclear methods of reducing the havoc caused by these insects are showing considerable success, after years of research. The sterile-male technique, first demonstrated in the southern United States against a cattle pest, is now being used against fruit flies in Central America and on the island of Capri. Projects in other countries using the sterile-male technique include control of a destructive sugarcane pest in Indonesia, a pine caterpillar in Korea, a cotton pest in Peru, and locusts in Russia.

Radioisotope tracers were used in many studies to establish heretofore unknown facts about various insects and their habits. A special session was held on the tsetse fly to review current research in Kenya, Nigeria, Uganda, the United Kingdom, and Austria. Radiation may be able to induce genetic changes such as degrees of sterility through more than one generation. Data from Israel showed that if cave ticks are allowed to feed on blood one time after being irradiated, they can be released to bite no more. Researchers in the United States have orbited wasps in satellites and recovered them to study the effects of space radiation; no results are available yet.

Tracers in a Ghana study showed that the cocoa capsid, a major pest damaging cocoa production, is itself the prey of about 30 other insects. French researchers added radioactive gold to honey and obtained information about the importance of the bumblebee to pollination. Another result reported by the French was that irradiation of silkworms can stimulate them to greater output. Aphid studies from the Federal Republic of Germany and Belgium gave data on the relationship between the insects and the plants they live on as well as the life history of aphids. An interesting result from India was that, after moths, which have eggs laid in them by parasitic wasps, were irradiated, the eggs then hatched to produce much greater quantities of male than female wasps. A tracer study in Sweden on conifer weevils showed that conifer plantations are most efficiently operated by concentrating control methods on the perimeters of the plantations.

Radioactive tracers were also used to study the use of insecticides. High temperatures make some insecticides less effective, according to U. S. workers. Some insecticides make the insect sterile instead of killing it; this could be in some cases more practical than radiation sterilization. Workers in the Federal Republic of Germany and in India studied the dynamics of insecticides in the bodies of mosquitoes and locusts.

A major study in Switzerland covering 12 years has made it possible to predict movements of the cockchafer. This beetle can survive refrigeration for years. A number of European countries are interested in tests that show that the irradiation method, used during the white grub stage, can effectively control this pest.

Availability of Isotopes and Services

ORNL Stable-Isotope Inventory Augmented

Recent additions to the ORNL enriched stable-isotope inventory include the following:

Isotope	Purity, %	Amount available, g
^{48}Ca	52.4	0.3
^{87}Sr	93.3	13.7
^{148}Nd	93–95	24.4

AEC Activities

AEC Withdraws from Production and Distribution of ^{60}Co

Effective in mid-March, the Atomic Energy Commission officially completed withdrawal from production and distribution of ^{60}Co. This latest action covers AEC sale of sources with less than 45 curies/g activity; earlier, AEC withdrew from sale of sources of higher activity. This decision is in accordance with AEC policy to withdraw from isotope production and distribution whenever private industry demonstrates its ability to assume the market load. The AEC will continue to meet requests for ^{60}Co when the purchaser certifies a need for a quality or quantity of the material that is not available commercially. It will also honor orders accepted before the withdrawal date.

Sanders Nuclear To Study ^{170}Tm

The AEC has awarded Sanders Nuclear, a joint-venture firm of Sanders Associates, Inc., and Cambridge Nuclear, a 1-year contract of $241 thousand to study the use of ^{170}Tm as fuel for isotope power sources. The work will be primarily on encapsulation compatibility and material properties, and the AEC will provide the ^{170}Tm. This radioisotope is considered most competitive with ^{210}Po; both have relatively short half-lives.

NASA/AEC Radioisojet Developed

A radioisotope-heated thruster for space applications has been developed by a joint NASA/AEC program. The unit uses ^{147}Pm to heat ammonia above 1650° F; the specific impulse of the unit is 230 sec at 22 millipounds thrust. The chief application of such a thruster will be to provide means of attitude stabilization and orbit adjustment for 24-hr synchronous satellites.

AEC Asks for Comments and Suggestions on Withdrawal from Radioisotope Production

The AEC first withdrew from production of some radioisotopes in 1961; the most recent radioisotope withdrawal is low-specific-activity ^{60}Co. The AEC earlier withdrew from other specific-activity grades of ^{60}Co. Because the radiation industry and private radioisotope suppliers are becoming increasingly active and competent, the AEC will eventually withdraw from production of most, if not all, radioactive materials. When and how remain to be decided.

Possible changes in the current production and distribution program are being studied by the AEC with the assistance of isotope producers and users. There are several possibilities: (1) AEC would distribute radioisotopes only through AEC- or state-licensed suppliers. AEC would not sell directly to users. (2) AEC would produce and distribute radioisotopes as a reactor service irradiation. The unprocessed targets would go to the paying customer for separation. (3) Some combination of these two steps could be worked out. (4) AEC would withdraw entirely from radioisotope production and distribution and make its capabilities available for this purpose on an ad hoc basis to the extent that private facilities were unavailable or inadequate.

A study by DID, to be completed in a year, will consider industry's interest in such arrangements, industry's ability to meet customer demands, the effect on prices, the effect on research and development costs, and the effect on AEC's legal responsibilities. Interested outside groups representing major radioisotope producers and users will be asked for comments.

Hanford Separates Largest Amount of ^{244}Cm

From spent fuel elements, Atlantic Richfield Hanford Company's contractor, Battelle–Northwest, has separated the largest single quantity of ^{244}Cm ever produced. About 4000 curies were separated and will be used at Oak Ridge National Laboratory for studies relevant to the SNAP program and other research.

25th Anniversary Films on Atomic Energy Now Available from USAEC

Two popular-level 16-mm color motion films are now available from the AEC for public showings; they were issued for observance of the 25th anniversary of the first sustained nuclear chain reaction. "The Day Tomorrow Began" in 30 min covers the building and testing of the first atomic pile by interviews, historical film footage, and paintings. "Guardian of the Atom" reviews the AEC's responsibilities and actions in developing the many uses of nuclear energy. Be-

sides showing the production of enriched uranium, the film covers various peacetime applications of nuclear energy in space, propulsion, agriculture, medicine, industry, food pasteurization, nuclear power stations, high-energy physics, controlled fusion, nuclear safety, nuclear explosives for excavation and development of natural resources, and other uses. Both films are available free (except for return postage costs) from the Motion Picture Film Library, U. S. Atomic Energy Commission, Oak Ridge Operations, P. O. Box E, Oak Ridge, Tenn. 37830.

General

Wood–Plastics in England Developed for Tableware

The first commercial development of wood–plastic composites (WPC) in England has been announced by the firm of Joseph Rodgers & Sons, who manufacture table cutlery. Cutlery with wooden handles is becoming increasingly popular, and using a WPC for the handle eliminates problems that are caused by soaking wooden handles when cleaning the knives. The irradiation will be done at the United Kingdom Atomic Energy Authority's (UKAEA) facility at Wantage. The sycamore wood will be impregnated with a styrene and acrylonitrile copolymer and given a 1.5-Mrad dose. The product will be marketed under the brand name "Manhattan-99."

Germans Install AECL Gamma Unit for Medical Sterilization Plant

Firma Willy Rusch, a West German manufacturer of rubber, latex, and plastic medical instruments, recently announced the completion of its radiation-sterilization facility. The gamma source, shielding, and conveyors were designed and constructed by Atomic Energy of Canada Limited (AECL). This new facility in Stuttgart can process about 1.2 tons/day at 2.5 Mrads. Although AECL's initial loading was only 90 thousand curies, the facility will hold 1.5 million curies, making it the largest facility in Europe. It is scheduled to start operation in July 1968; additional loadings of ^{60}Co will be used as the demand increases.

India Checks Pollution from Fossil-Fueled Power Station

Indian authorities report the use of ^{46}Sc to follow fly ash dumped at sea. The fly ash was waste from the Ennore Thermal Power Station in Madras. The labeled fly ash was followed at sea for more than a month by underwater radiation detectors before the dumping site was approved.

New England Nuclear Expands

A recent announcement by New England Nuclear Corp., Boston, states that the company has acquired a 55-acre tract in Billerica, Mass., to be used to expand the firm's radiopharmaceutical manufacturing capability.

Panametrics Recommends Aircraft Taxi Guidance System Using ^{85}Kr to FAA

Panametrics, Inc., has submitted a recommendation to the Federal Aviation Agency (FAA) on the construction of a prototype radioisotope taxi guidance system. The system would be based on ^{85}Kr enclosed in a pipe buried beneath the runway center line. Stationary avionic gamma-ray detectors surrounded by rotating collimators would sense the lateral position of an airplane in relation to the line source of radiation.

The FAA has specified detection of lateral position to ±5 ft, with the system operable to 30 ft when the aircraft is moving at 30 mph. The Panametrics recommendation includes modifications in shielding and the pumping system of an earlier experimental system.

New Canadian Hospital First To Include Radiation-Sterilization Unit

The planned $35-million University Hospital at the University of Western Ontario, London, Ontario, will be the first hospital in the world with its own gamma sterilization unit. Dr. John E. Neilson, hospital director, says the unit will cost $300 thousand, be contained in a 400-sq ft shielded chamber, and be designed and built by Atomic Energy of Canada Limited. The irradiator, an adjunct to the 450-bed hospital, will use ^{60}Co as its source.

Neilson pointed out that radiation sterilization is very uneconomical in terms of cost per ton of sterilized product when compared to conventional steam sterilization. However, there are many items used in hospitals which cannot be sterilized by steam for various reasons. These items include anesthetic apparatus; parts of heart, lung, and dialysis machines; and various optical instruments used inside the human body. The University Hospital will include a conventional sterilizing system in addition to the gamma unit.

Bechtel Corp. Receives Chicago Contract

The Metropolitan Sanitary District of Greater Chicago has awarded a third contract in its study of radiation processing of sewage. This contract for $65 thousand goes to the Bechtel Corp to study gamma-radiation treatment of sewage and industrial waste. Chicago has already awarded contracts to Purdue Research Foundation and Battelle–Northwest

for related studies [see Miscellaneous Section, *Isotopes and Radiation Technology*, 5(3): 264 (Spring 1968)]. The sanitation district wants to investigate the possibility of converting their secondary-treatment process to a tertiary treatment of wastes using radiation.

UKAEA Shipment to Sweden Is World's Largest

The United Kingdom Atomic Energy Authority has shipped 215 kilocuries of ^{60}Co to Sweden. This is reputed to be the record for shipment of radioactive material between countries. The ^{60}Co will be used in a process radiation plant being built by H. S. Marsh Nuclear Energy Ltd., for Radona A.B., a Swedish firm. The plant will sterilize medical items; it has a capacity for 1 million curies of ^{60}Co if operations increase to the point that this large a source is needed.

UKAEA Develops New RIPPLES

The United Kingdom Atomic Energy Authority has announced the development of a new series in its line of radioisotope power generators. Whereas the old group was known as the RIPPLE series, the new line will be called the RIPPLE-X series. UKAEA is claiming a new technique that brings system efficiency to about 5%. The new generators will be designed to produce from 8 to 40 watts after 5 years of operation. UKAEA is also predicting that with eventual domestic production of ^{90}Sr, the power fuel, RIPPLE generators will cost only half what they do now.

Popular Science Gives Tips on Working with Wood-Plastics

The March 1968 issue of *Popular Science* (R. J. DeCristoforo, A Home-Shop Test of Irradiated Wood, pp. 166-173, 190) gives tips for the home craftsman on working with wood–plastic composites (WPC). The author worked with Novawood, a product of American Novawood, Lynchburg, Va., and the article lists several kits available from American Novawood at prices from $1.65 to $50.

The author points out to the reader that he can do anything with Novawood that he can do with wood except for nailing. He gives the following tips: (1) Expect cutting tools to dull faster. (2) Work slower than usual when cutting, drilling, or turning to prevent pileup of plastic on the cutting edge of the tool. (3) For bandsaw cutting, use a blade that cuts nonferrous metals as well as wood; for saber saws, use metal-cutting blades but not the hacksaw type. (4) Use spade bits for drilling. (5) Stay with a scraping action when working WPC on a lathe; do not try fancy gouge and skew techniques. Also, use slightly higher speeds than for untreated wood. (6) Finishing the Novawood is easier than finishing untreated wood since the luster is already built in. The process is one of polishing with successively finer grades of sandpaper followed by rubbing with rottenstone and then cleaning and polishing with a soft cloth. Surface damage is quickly repaired by repeating the finishing procedure over the damaged spot.

More on NUMEC's PermaGrain

Nuclear Materials and Equipment Corp. (NUMEC) has released more details on its new wood–plastic product. PermaGrain is a flooring material made by impregnating red oak with methylmethacrylate monomer and a dye, then irradiating it in a ^{60}Co cell to polymerize the plastic in the wood. NUMEC, with the assistance of its parent company—ARCO Chemical Division of Atlantic Richfield, has completed market analysis and will soon start market testing of PermaGrain made up as parquet tiles. NUMEC expects that the best market will be in the institutional field and that PermaGrain should be competitive with vinyl tile and terrazzo, but no official price list has yet been issued. It will be promoted by emphasizing its superior wear resistance and its look—that of natural wood.

U. S. Army Natick Laboratories Asks Bids on Cesium Irradiator

The U. S. Army Natick Laboratories have asked for proposals on a food irradiator for which the source will be 250 kilocuries of ^{137}Cs. Natick wants more cesium experience in treating configurations and package sizes needed for military rations. Solicitations have been sent to Gamma Process Co.; Knapp Mills, Inc.; Isotopes, Inc.; U. S. Nuclear Corp.; Lockheed-Georgia Co.; Battelle Memorial Institute; Atomics International; and Atomic Energy of Canada Limited. Natick hopes to have the facility operating within a year.

Selected Literature

Customer List for FY 1967 Now Available

The Isotopes Information Center of Oak Ridge National Laboratory has recently published its annual compilation of AEC radioisotope customers. The report, ORNL-IIC-13, entitled *List of AEC Radioisotope Customers With Summary of Radioisotope Shipments, FY 1967*, is available from Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Va. 22151, for $3.00. This 37-page report gives data on the AEC's 459 customers and what isotopes they purchased; it does not list how much of any isotope an individual customer bought. The report also summarizes the value and number of shipments for each isotope.

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